Lone Pine Dam Ground Water Recharge Evaluation

Prepared for

Navajo County

by

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Introduction

This report was prepared as part of a larger project, *Show Low Creek Reservoir System Evaluation and Recommendations*, completed by NAU in late 2002, and provides an estimate of the probable aquifer recharge benefit(s) offered by the existing Lone Pine dam and reservoir on Show Low Creek.

The Lone Pine dam foundation, reservoir floor and walls consist in places of the Permian-age Kaibab Formation, which has numerous fissures and cavernous openings in the area of the impoundment (see Kiersch, 1958). *It has been suggested that the impoundment may be important for aquifer recharge*. This potential benefit, which hadn't been previously quantified, has remained as a justification for maintaining the existing impoundment.

As part of our proposal to Navajo County for the *Show Low Creek Reservoir System Evaluation and Recommendations*, we committed to an evaluation of the probable benefit of Lone Pine dam and reservoir. This was to include: researching historical and anecdotal information, reviewing the literature to identify appropriate techniques for estimating recharge rates, researching and possibly developing a method of our own, and applying one or more of these methods to estimate probable annual recharge rates due to the impoundment.

The evaluation presented in this report provides an estimate of the probable recharge at Lone Pine reservoir during a year with average precipitation; this estimate is then compared to an estimate of ground water recharge, occuring during a year with average streamflow, that is available to the regional ground water pumping center in Snowflake, Taylor and Shumway. Throughout our study, when necessary, we have made assumptions that reflect, in our best judgment, the most-likely state of affairs. We have not made conservative assumptions, which would only to serve to drive the estimate of Lone Pine dam and reservoir aquifer recharge benefit to a large but improbable value.

Existing Reports and Data

Early relevant studies included: Harrell and Eckel (1939); Johnson (1962); Nickell, 1939 and the U.S. Bureau of Reclamation (1947). Kiersch (1958) summarized the geology of the Lone Pine reservoir site. More recently, Mann (1976) completed a ground water assessment of southern Navajo County. The material presented in this section is largely from these works. Note that past water resources and ground water investigations in the region have not addressed aquifer recharge in any serious way.

Lone Pine dam and reservoir area bedrock geology consists of exposures of Permian age rocks –Kaibab Formation limestone and sandstones. At the site, the Kaibab Formation is underlain by the Coconino Sandstone (Hopkins, 1990). Triassic sediments, the Pliocene Bidahochi Formation and Quaternary basalt exist higher up on the reservoir walls, near the dam abutments and in the spillway area. Quaternary alluvium (sediment) is found in these areas as well.

In the vicinity of Lone Pine, the principal aquifer is the Coconino, or C, aquifer, which is defined to include the Coconino Sandstone, the underlying upper portion of the Schnebly Hill Formation (Neal and Johnson, 2001) and the overlying Kaibab Limestone. It is important to note that, prior to Blakey's (1990) work defining the Schnebly Hill Formation, the Supai Formation, which is below the Schnebly Hill Formation, was considered to be the lowermost formation of the Coconino aquifer.

The general direction of Coconino aquifer ground water flow is from recharge areas near the Mogollon Rim, in the south, toward the Little Colorado River, in the north. In the area of Lone Pine dam and reservoir, the Coconino aquifer is unconfined. To the east and north, there are limited areas in which the aquifer is confined.

Downstream from Lone Pine dam, the Coconino aquifer is confined, and is extensively pumped to supply water for municipal, irrigation and industrial uses in the communities of Snowflake, Taylor and Shumway, *referred to in this report as STS*. In 1953, nearly 6,500 ac-ft of water was withdrawn by pumping. By 1972, withdrawals had grown to nearly 25,000 ac-ft/yr. Between 1951 and 1972, the potentiometric surface, or water table, correspondingly declined from 5 to 50 ft, depending on the specific location – see Mann's (1976) figure 6, which is reproduced in this report in Appendix 1.

We obtained stream flow data, summarized below, from the U.S. Geological Survey (waterdata.usgs.gov/nwis/discharge) for Show Low Creek in the vicinity of Show Low and Lakeside.

Site Number	Site Name	Site Name	From	To
09390500	SHOW LOW CREEK NEAR LAKESIDE, ARIZONA	Latitude: 34°10'46" Longitude: 109°59'14" NAD27 Drainage area: 68.60 sq. mi. Gage datum: 6,610. ft above mean sea level NGVD29	1953-05-01	2001-09-30
09391000	SHOW LOW LAKE NEAR SHOW LOW, ARIZONA	Latitude: 34°11'45" Longitude 110°00'12" NAD27 Drainage area 73.00 sq. mi. Gage datum: 6,500. ft above mean sea level NGVD29	1985-10-01	2000-09-30
09392000	SHOW LOW CREEK BELOW JACQUES DAM, NEAR SHOW LOW, ARIZONA	Latitude: 34°11'47" Longitude: 110°00'13" NAD27 Drainage area: 73.00 sq. mi. Gage datum: 6,530. ft above mean sea level NGVD29	1955-10-01	2001-09-30
09392500	SHOW LOW CREEK AT SHOW LOW, ARIZONA	Latitude: 34°15'10" Longitude: 110°01'40" NAD27 Drainage area: 90.2 square miles Gage datum: 6,309. ft above mean sea level NGVD29	1944-10-01	1955-06-30

The record from Show Low Creek at Show Low is brief. The gage at Jacques Dam, which impounds Show Low Lake, is a few miles upstream from Show Low. Even though Show Low Creek, after passing Jacques Dam, does go through Fool's Hollow Lake, which will have an impact on the hydrograph, we believe that, during periods when reservoirs on the system are full (e.g., during time intervals of high flow, such as winter 1992-1993, the highly-controlled and attenuated Jacques Dam hydrograph would be similar to that of Fool's Hollow Lake. Though Show Low Creek is highly controlled by several dams, during high-flow periods, this Jacques Dam gage is the closest representation of an average annual hydrograph at Lone Pine. Hydrographs from 1968 and 1991 represent the average annual hydrograph for the period of record, 1955 to 2001, for the Jacques Dam gage.

The closest gages downstream from Lone Pine are on Silver Creek. We did not use these gage data because the gages are close to large irrigation diversions. We looked for stream gages for catchments that were hydrologically similar to that of Lone Pine, but again, this task was fruitless because of the highly-controlled nature of Show Low Creek.

We completed an exhaustive search for other measured data in the Lone Pine area that would have some credibility as a representation of what an average annual hydrograph for Show Low Creek in the area of Lone Pine reservoir might look like, but we were unsuccessful. Sources contacted included the USGS, ADWR, Arizona State Parks, US Forest Service, and the NRCS.

We elected to use the record from Show Low Creek Below Jacques Dam for our evaluation.

At first glance, it may seem difficult to generalize from the available stream flow data at Jacques Dam to stream flow at Lone Pine because of the intervening diversions, storage and additions or losses (abstractions) to stream flow that occur in the channel between Show Low Lake and Lone Pine. However, a cursory examination of the map of distribution of average annual precipitation across that portion of the Show Low Creek watershed that is tributary to flow at Lone Pine is revealing and useful. The roughly 50% of the watershed area (73 sq. mi.) that is tributary to flow at the Jacques Dam gage has average annual precipitation that ranges between 23 in/yr and 32 in/yr. The other roughly 50% of the watershed area (85 sq. mi.) has average annual precipitation that ranges between 16 and 23 in/yr. Additionally, anecdotal information (U.S. Bureau of Reclamation, 1947) indicates that Linden Wash, the main tributary to Show Low Creek below Show Low and above Lone Pine dam, flows only during floods.

Therefore in scaling the flow record at Jacques Dam to what we might expect for a gage immediately upstream of Lone Pine, rather than a factor of two (similar precipitation ranges for the two portions of the watershed), we estimate that a factor of approximately 1.33 will be appropriate. *For this evaluation, we scaled the Jacques Dam gage record by a factor of 1.33 and used the scaled record for evaluations of average annual recharge due to the Lone Pine impoundment.*

We also completed a comprehensive search for data on measured recharge to the Coconino aquifer, but again, were unsuccessful. Leads followed included investigations at Navajo County, Silver Creek Irrigation District, several departments at ADWR, USGS, Arizona Game and Fish, U.S. Army Corps of Engineers, the Internet, and the Cholla power plant, west of Holbrook.

Aquifer Recharge Mechanisms

Recharge of aquifers generally occurs (Gee & Hillel, 1988) by means of:

- *diffuse*, or continuous pathways;
- *discrete*, or discontinuous pathways.

The first mechanism involves water transport through pore space, primarily in soils. It is a mechanism that we expect to be important in areas that have pervasive soil that is periodically saturated by rainfall or snowmelt during the course of an average year. That is, there must be sufficient precipitation available to drive moisture from the surface into the subsurface. Contrast this with an arid region, in which a soil might initially soak up some moisture, but shortly return it to the atmosphere due to high rates of evaporation and transpiration. The second mechanism provides relatively large pathways, such as fissures, fractures, faults, joints, sinkholes and other openings in surficial soil or rock through which water can rapidly pass to an underlying aquifer.

Both mechanisms are anticipated to be important in the area around Lone Pine and toward the Mogollon Rim, to the south. However, given the hydrogeology of the region, discrete pathways are believed to be especially significant for ground water recharge.

Methods Available for Estimating Recharge

There are a variety of methods available for estimating ground water recharge in arid regions (Gee & Hillel, 1988; King, 1992; Flint et al., 2002). Generally, these fall into three categories:

I. Estimates based on equations, which can be based on relationships developed from theory (*theoretical*) or deduced from observational data on real systems (*empirical*). A hybrid approach might combine these two approaches.

II. Estimates based on numerical simulation (numerical model) of the surface and subsurface hydrological system in question or on a suitable reference system. Generally, the numerical models used have some basis in ground water or surface water theory, or in heat transport theory.

III. Physical measurements. On the one hand, these permit estimation of either the net vertical water flow or the flux of a chemical tracer (e.g., Dettinger, 1989) that allows estimation of net vertical water flow. On the other hand, measurements of changes in the earth's gravitational field may be used to estimate changes in unconfined aquifer storage, which, if pumping is known, may allow estimation of recharge (Pool and Schmidt, 1997).

Flint et al. (2002) provided a state-of-the-art assessment of methods from all three categories as applied to a recharge evaluation in the arid Yucca Mountain region of southern Nevada.

Methods Used for Estimating Recharge

For our evaluation, we used methods from all of the above categories.

- ***Recharge at Lone Pine reservoir – 1993 flood events.*** We used a unique 1993 record of Lone Pine reservoir stage versus time, collected by Navajo County staff, to estimate recharge in the reservoir area (category III). This application yielded a recharge function (volumetric recharge rate versus stage) for the Lone Pine Reservoir. As guidance for this approach, we developed a 'ballpark' estimate of the recharge function using other historical information on Lone Pine reservoir performance.

- ***Recharge at Lone Pine reservoir during a year with average precipitation.*** The recharge function developed above, in conjunction with an annual Jacques Dam hydrograph for a typical calendar year (1968), scaled so as to be appropriate for the reservoir location, was applied in a numerical simulation (category II) to estimate water recharge at Lone Pine reservoir during a calendar year with average streamflow.

The above approach was used to obtain an estimate of how much water is likely contributed by Lone Pine dam/reservoir to recharge during a year with average streamflow.

This quantity must be put in the context of an estimate of average annual *regional* recharge. The choice of *region* can be either the watershed area that is tributary to Lone Pine reservoir, or, to the Coconino aquifer recharge area that provides water to the regional ground water pumping center in STS.

- ***Regional recharge – considering the area of that portion of the Show Low Creek watershed that is tributary to Lone Pine reservoir, during a year with average streamflow.*** For the portion of the Show Low Creek that is tributary to Lone Pine reservoir, we applied the empirical approach (category I) to estimate average annual recharge to the drainage basin above Lone Pine dam during a year with average streamflow.

- ***Regional Recharge – looking at the area of the Coconino aquifer that contributes to ground water resources tapped in the STS area.*** For the estimated area ('capture zone') that contributes to the ground water resources in the STS area, where significant ground water pumping occurs, we applied the empirical approach (category I) to estimate recharge to this capture zone during a year with average precipitation.

For this report, the estimate of regional recharge based on the capture zone approach was preferred, because the Coconino aquifer's boundaries extend significantly beyond the Show Low Creek watershed boundaries.

Recharge Estimates

First of all, a 'ballpark' estimate of the seepage rate and the recharge function at Lone Pine can be developed from available historical data.

Kiersch (1958) reported historical data on reservoir performance at Lone Pine: during a fall in water level from 74 ft on April 7, 1936 to 43 ft on May 8, 1936, nearly 5700 ac-ft of water were lost in 31 days. *This loss estimate assumes no inflow, evapotranspiration or head-gate bypass*. With these assumptions, which are not all conservative (if inflow occurred, the actual volume of water lost in 31 days would be greater and seepage higher), the average seepage rate is 184 ac-ft/day. A constant rate recharge function (Figure 1) can be developed for the range of stage, 31 ft, to which these observations apply. A possible linear recharge function is also illustrated in Figure 1. The linear function is more realistic than the constant rate, and in the absence of other information is the most plausible.

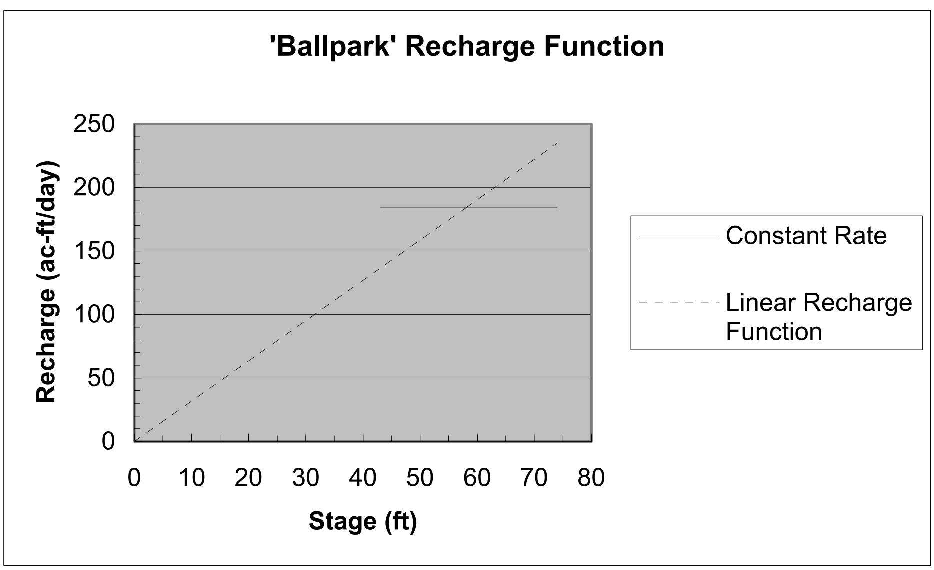

Figure 1: Approximate recharge functions based on 1936 reservoir performance data provided by Kiersch (1958).

As mentioned above, a record of stage versus time at Lone Pine for a series of reservoir filling precipitation/snowmelt events in 1993 is available from an unpublished report (ECI, 1994). See Figure 2. This record was originally used by ECI to estimate the daily 'sinkhole outflow' rate as a function of reservoir stage. ECI wasn't concerned with whether this 'outflow' went to aquifer recharge or appeared as flow under/around the dam. ECI (1994) estimated that approximately 5,300 ac-ft of water was lost during the portion of the precipitation/snowmelt events from March 1, 1993, to April 12, 1993.

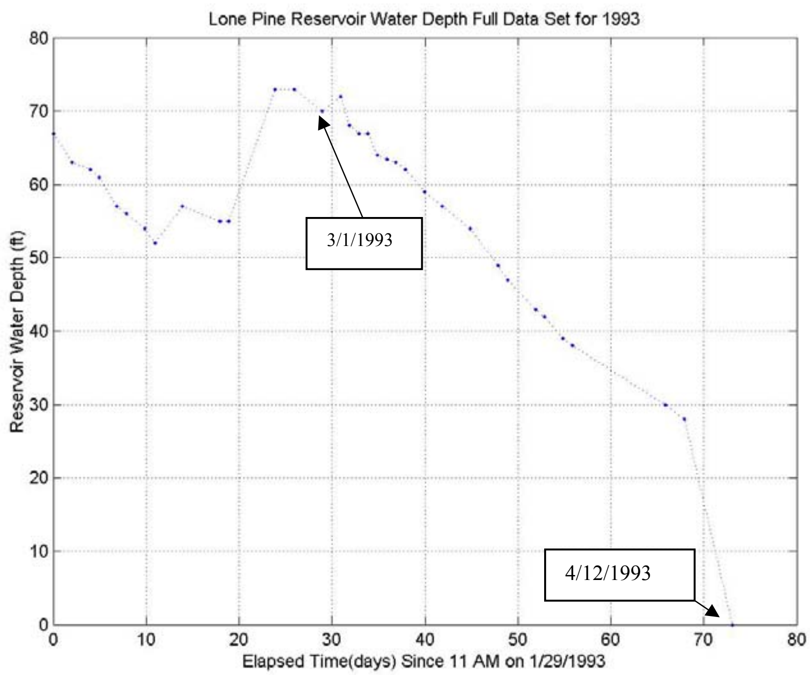

Figure 2: Record of stage versus time for reservoir filling events in early 1993 (data from ECI, 1994).

We conducted a somewhat different analysis using a portion of the same unique record of reservoir stage versus time at Lone Pine. We used using MATLAB software to analyze the portion of the record from March 1, 1993 to March 26, 1993 – because the record of stage versus time (Figure 2) is missing data for the 9-day period from March 26, 1993 to April 5, 1993. During this period, we believe, based on the Jacques Dam hydrograph for the period (Appendix 2), that there was significant inflow to the reservoir, which significantly impacted the subsequent stage data. From the March 1, 1993 to March 26, 1993 record, and subject to several assumptions, discussed below, a *recharge function* for the reservoir has been developed – see Figure 3.

The recharge function (Figure 3) is an estimate of the daily volumetric seepage loss, or daily infiltration, as a function of reservoir stage. This function is well-defined for stages between approximately 965 ft and 995 ft (with 925 ft being the outlet invert elevation). The function has been estimated for stages less than about 965 ft. Observations on the number and distribution of 'sinkholes' (e.g., Kiersch, 1958; U.S. Bureau of Reclamation,

1947) suggest a distribution of sinkholes over a wide range of reservoir elevations and a preponderance of sinkholes at moderate elevation. This distribution leads us to conclude that seepage probably declines rapidly once reservoir stage drops below about 960 ft. (Prior to the early 1970's, when the outlet was repaired, there were 'sinkholes' associated with leakage around the outlet pipe – see U.S. Bureau of Reclamation, 1947).

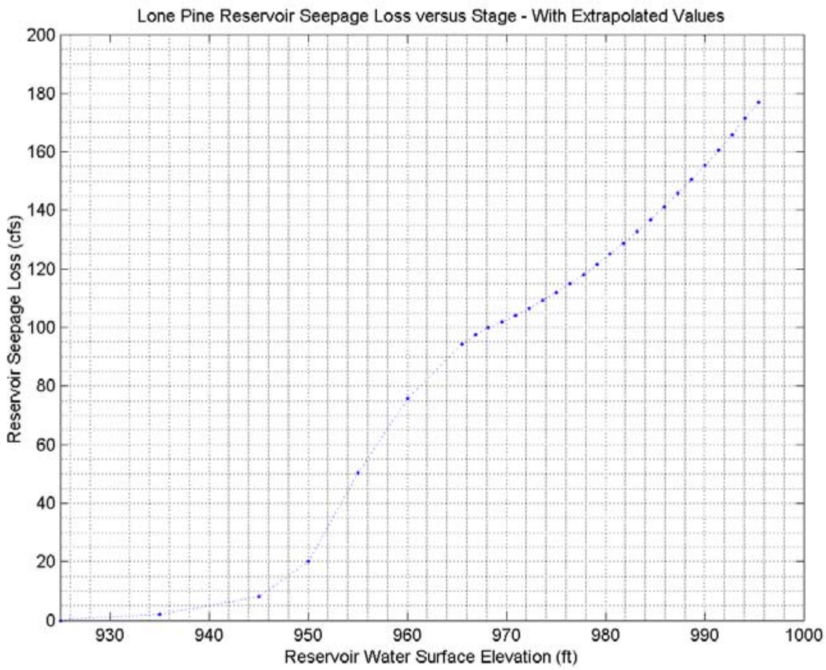

Figure 3: Smoothed recharge function developed from data available for Lone Pine reservoir. Seepage at stage less than 965 ft is extrapolated.

During the portion of the record from March 1, 1993 (reservoir full) to March 26, 1993, we estimate that approximately 5,900 ac-ft of water infiltrated (seepage), approximately 3,300 ac-ft of water passed through the primary outlet, and approximately 1,600 ac-ft of water flowed into the reservoir.

Incidentally, the range of stage considered in our analysis is very similar to that considered by Kiersch (1958). For this range, we estimate that the daily seepage loss averages 250 ac-ft, which compares reasonably well with our 184 ac-ft 'ballpark' estimate developed from Kiersch's data. One possible reason for the discrepancy may be that we were able to estimate inflow, whereas Kiersch could not.

The key assumptions that we made are as follows:

1) We linearized the record of reservoir stage versus time for the period March 1 thru March 26. This was done to minimize oscillations in the numerical analysis of data that are, in fact, imperfect.

2) We linearized the inflow record for the same reason. The inflow record used, as discussed above, is from the gauge below Jacques Dam. We scaled the record by 1.33. *When estimating seepage, neglecting inflow will cause the seepage to be underestimated*.
3) We developed a reservoir capacity versus stage curve using information from the available geotechnical reports for Lone Pine and Schoens dam.
4) We used an outflow discharge rating curve, developed using Haestad Methods Pondpack software, assuming a Manning coefficient of 0.013 for the 24" Techite (reinforced fiberglass encased in concrete) discharge pipe, and assuming a square-edged inlet with headwall.
5) We neglected evaporation and transpiration losses, which is a safe assumption for the time period under investigation.
6) Whereas there is documentation in ADWR files that flow passes under and around the dam and appears downstream as surface water flow, we assumed, for this part of our analysis, that all seepage losses go to recharge of the Coconino aquifer (conservative assumption).

Supporting documentation, including graphs that illustrate the complete results of our simulation and analysis appears in Appendix 2.

Next, the recharge function developed for Lone Pine reservoir was applied in a numerical simulation (category II method) to estimate ground water recharge at Lone Pine during a calendar year, 1968, with average streamflow – based on data for the Jacques Dam gage on Show Low Creek, to estimate the inflow to Lone Pine. Haestad Methods Pondpack software was used to conduct this simulation, which is documented in Appendix 3. *Using a scaled streamflow record (scaling factor of 1.33, discussed above), and assuming that 90% of the water lost as seepage appears as ground water recharge (with the other 10% going around and under the dam) we estimate that nearly 2,200 ac-ft of water recharges the Coconino aquifer at Lone Pine reservoir during a calendar year with average streamflow on Show Low Creek.*

Of the category II empirical methods, we applied two methods to estimate the average basin-wide recharge during an average year for Show Low Creek. The first was the Maxey-Eakin (Maxey and Eakin, 1949; Avon and Durbin, 1994) and the Anderson et al. method (Anderson et al, 1992). The Maxey-Eakin method is based on analysis of data for basins in east-central Nevada. The Anderson et al. method is based on regression analysis of results from numerous ground water simulations for *alluvial* basins in southern Arizona.

Average annual precipitation data, based on the years 1961 to 1990 (from the Western Regional Climate Center – WRCC – www.wrcc.dri.edu/precip.html) were viewed, edited and transformed (to UTM coordinates) with ESRI's ArcGIS Map software and then exported for use with Autodesk's Land Development Desktop (LDD) software. LDD was used to create a map that showed precipitation contours and the watershed boundary.

The watershed boundary was created as a polygon over a background of raster images of topography from U.S. Geological Survey 7.5-minute quadrangle maps and is the area of the Show Low Creek watershed tributary to Lone Pine reservoir. Polygonal boundaries of constant-precipitation regions were created in LDD and their areas were determined using LDD tools.

For that portion of the Show Low Creek watershed that is tributary to Lone Pine reservoir, our application of the Maxey-Eakin method leads to an estimate of average annual recharge of nearly 45,000 ac-ft. Applying the Anderson et al. method yields an average annual recharge estimate of only 6,200 ac-ft.

The Maxey-Eakin method leads us to conclude that nearly 23% of total basin precipitation ends up as ground water recharge whereas the Anderson et al. method leads to the conclusion that just 3% of total basin precipitation volume ends up as recharge.

While these empirical methods provide only estimates, in this case, the estimates widely diverge. In an effort to resolve the discrepancy, we reviewed references pertinent to each method to identify which is most appropriate for the study area.

The basins considered by Anderson et al. (1995) were alluvial basins, primarily in the southern Arizona Basin and Range province, that were treated as relatively pervious alluvial deposits (gravels, sands, silts and clays) over impervious rock. Furthermore, Anderson et al. (1995) calibrated their regression equation using numerical ground water flow simulation results for 12 basins in southeast, south central and western (Colorado River area) Arizona. The physiography, climate and hydrogeology of these basins are very different from those of the Show Low Creek watershed.

On the other hand, Maxey and Eakin (1949) studied a group of basins that provide a better match to the Show Low Creek watershed, as far as climate, physiography and hydrogeology.

Additionally, we discussed the suitability of these two methods for the study area with several colleagues.

Finally, the Kaibab formation, which outcrops extensively in the region, has many openings and fissures that provide for enhanced ground water recharge – as evidenced by the performance of Lone Pine and Schoens reservoirs and the reputation of Show Low Creek in the area as a losing stream.

Our opinion is that the Maxey-Eakin method is the most appropriate method for this study. *For this project, we estimate that the average annual recharge for the watershed area tributary to Lone Pine reservoir is 45,000 ac-ft, which is the recharge obtained by applying the Maxey-Eakin method.*

A better approach is to consider the land surface area available to contribute recharge to the Coconino aquifer, which is tapped by the regional ground water pumping center in the STS area. Mann (1976) provided a map of the potentiometric surface for the Coconino aquifer in southern Navajo county. Additionally, Mann provided a map of the observed drawdown of the potentiometric surface in the STS area from spring of 1951 to spring of 1973 (Appendix 1). This drawdown reflected a then-current ground water withdrawal rate of nearly 23,000 ac-ft/yr.

We considered attempting to update Mann's map of observed drawdown in the STS area. ADWR completed a 'well sweep' in 2001 to gather new data on water levels in area wells. We successfully downloaded the required software and viewed the ADWR Imaged Records Database. This database consists of Adobe Acrobat PDF files of responses to ADWR's most recent well sweep questionnaires, which were sent to all well owners. The questionnaire responses offered potential for information about water level and well construction, but they also are susceptible to errors in reporting by the well owners. Also, the database does not contain maps of the well locations nor of the potentiometric surface. While it is, in principle, possible to piece together ADWR records to eventually create a new potentiometric surface, this task would have required considerable work outside of our scope.

We suspected that drawdown has only increased in the years since Mann (1976) completed his work and this has been confirmed. Specifically, the USGS has compiled information on ground water use in Arizona ground water basins (U.S. Geological Survey, 1994). The U.S. Geological Survey data indicate that ground water use in the STS area has grown from nearly 23,000 ac-ft/yr in 1972 to nearly 38,000 ac-ft/yr in 1990. *It is likely that ground water withdrawals in the STS area during 2002 are nearly double what they were when Mann conducted his study. Consequently, we believe that a decision to use Mann's (1976) data will, without correction, lead to an underestimation of the probable capture zone area that is 'tributary' to the regional ground water pumping center in STS.*

Utilizing Mann's maps of the potentiometric surface and the drawdown observed from 1951 to 1973, we estimated the 'capture zone' for the STS regional ground water pumping center. This capture zone is the approximate land surface area for which ground water recharge, assumed to move vertically downward to the Coconino aquifer, can flow to the STS ground water pumping center. In order to delineate the capture zone, raster images of Mann's maps were digitized and the raster images were imported into LDD. The images were appropriately scaled and overlayed, the potentiometric contours were digitized, and the capture zone was delineated. The capture zone area is estimated to be nearly 450 sq. mi. The contours of average annual precipitation for a data set that spans the years 1961 to 1990 were imported into LDD (procedure discussed above). Polygonal boundaries of regions of constant precipitation within the capture zone were created in LDD and their areas were determined using LDD tools.

Again applying the Maxey-Eakin method, we obtained an estimate of 69,000 ac-ft for annual ground water recharge in the capture zone 'tributary' to the regional ground water pumping center in STS – for a capture zone defined by 1972 pumping rates. This is nearly 16% of the total capture zone area precipitation volume. Documentation in support of this analysis appears in Appendix 4.

Assuming that the capture zone has grown by 50% in response to a growth in pumping by nearly 100% (1972 to 2002), the annual recharge in a capture zone defined by 2002 pumping rates is estimated to be approximately105,000 ac-ft. This assumption concerning capture zone growth could be tested with a regional transient ground water model constrained by the available cone of depression (drawdown) and pumping rate data, however, such an analysis was beyond the scope of our services on this project.

Summary and Conclusions

The recharge potential of Lone Pine reservoir has been evaluated. For a calendar year with normal streamflow on Show Low Creek, we estimate that the reservoir provides for approximately 2,200 ac-ft of recharge. The ratio of this quantity of recharge to the average annual recharge to the Coconino aquifer that is available to the regional ground water pumping center in Snowflake, Taylor and Shumway (105,000 ac-ft), is approximately 0.02, or 2%.

We estimate that Lone Pine reservoir, during a calendar year with normal streamflow on Show Low Creek, provides, *at most a few percent* of the average annual recharge to the Coconino aquifer that is available to the regional ground water pumping center in Snowflake, Taylor and Shumway. We acknowledge that, in all likelihood, different parties will view the significance of this number differently.

Acknowledgements

We would like to thank David Prudic of the USGS and Tom Anderson of Errol Montgomery and Associates for insight into their work on ground water recharge estimation and balances. We thank Saeid Tadayon of the USGS for providing information on ground water withdrawals in the Snowflake area and Tom Hieb of Navajo County for his help throughout this project.

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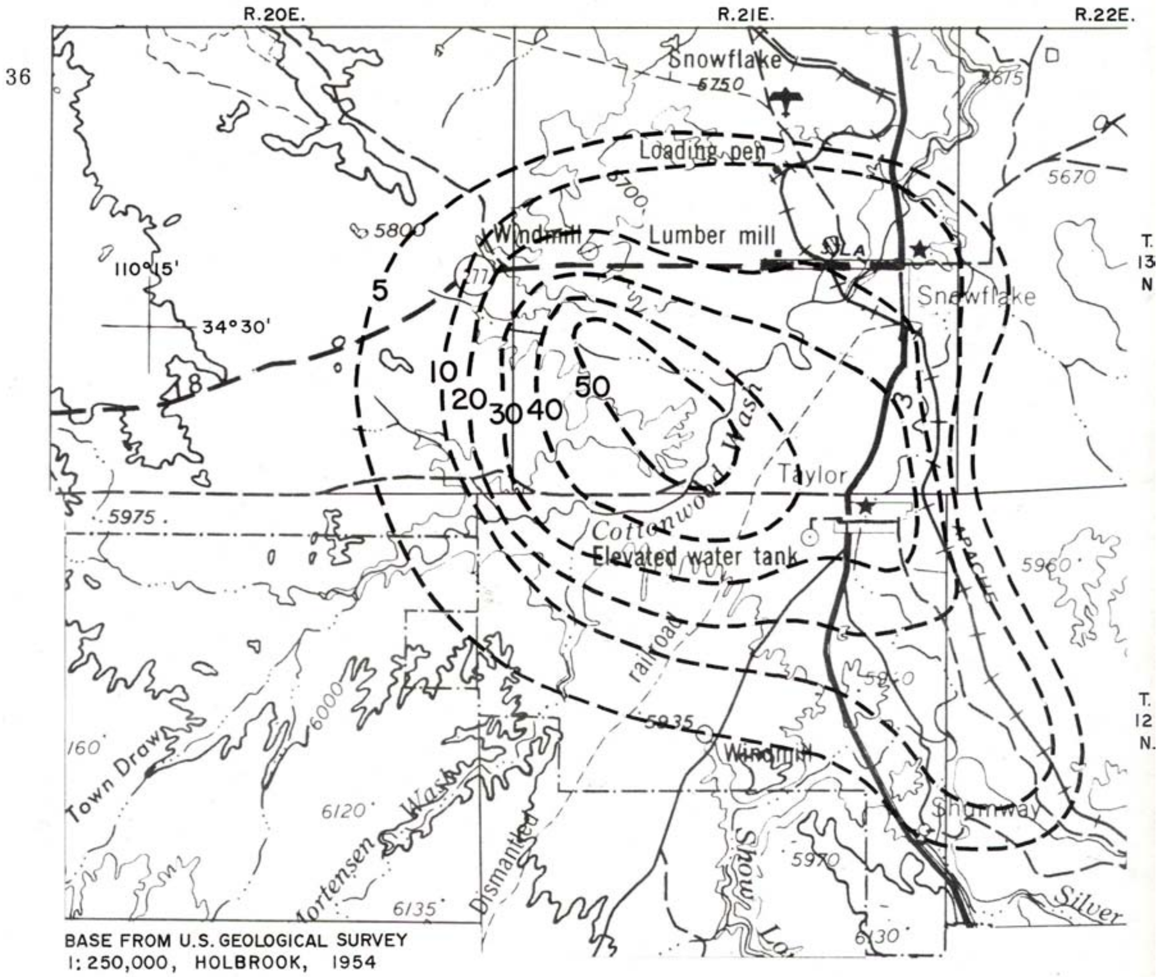
Appendix 1

Figure 6, reproduced from Mann (1976)



EXPLANATION

——50——— APPROXIMATE LINE OF EQUAL WATER-LEVEL DECLINE—INTERVAL 5 AND 10 FEET

0 5 MILES

0 5 KILOMETRES

CONTOUR INTERVAL 200 FEET

FIGURE 6.--WATER-LEVEL DECLINES, SPRING 1951 TO SPRING 1973, IN THE SNOWFLAKE-SHUMWAY AREA.

Appendix 2

Analysis of 1993 Seepage Record at Lone Pine Dam – Theory, Program Code and Graphs

Theory

stage (time)	$z_i(t_i)$	$[L]$	*known*
inflow (time)	$Q_{in_i}(t_i)$	$[L^3T^{-1}]$	*known*
discharge (stage)	$Q_{out_i}(z_i(t_i))$	$[L^3T^{-1}]$	*known*
area (stage)	$A_i(z_i(t_i))$	$[L^2]$	*known*
volume (stage)	$V_i(z_i(t_i))$	$[L^3]$	*known*
seepage (stage)	$Q_{S_i}(z_i(t_i))$	$[L^3T^{-1}]$	*unknown*

seepage includes flow under and around and through the dam
discharge is culvert discharge from the dam outlet
inflow is flow from Show Low Creek

Mass Balance Equation

[Initial Condition: $t = t_1$ is the reservoir-full condition; neglect evapotranspiration; $V(t) = V(z(t_1))$]

$$-Q_{out}(t) - Q_S(t) + Q_{in}(t) = \Delta\,\text{storage} = \frac{dV}{dt}$$

$$\int_{t_1}^{t_n} \left(-Q_{out}(z(t)) - Q_S(z(t)) + Q_{in}(t)\right)dt = \int_{V(z(t_1))}^{V(z(t_n))} dV = V(t_n) - V(t_1)$$

Finite Difference Approach:

$$-Q_{out}(z(t)) - Q_S(z(t)) + Q_{in}(t) = \frac{\Delta V}{\Delta t}$$

for a reservoir with declining stage:

$$\sum_{i=1}^{n}\left[-Q_{out}(z(t_i)) - Q_S(z(t_i)) + Q_{in}(t_i)\right]\Delta t_i$$
$$= V(t_n) - V(t_1)$$

and, solving for Q_S for *i=2, ..., n*:

$$Q_S(z(t_i)) = \left[Q_{in}(t_n) - Q_{out}(z(t_n))\right] + V(t_{n-1}) - V(t_n)$$

MATLAB Code

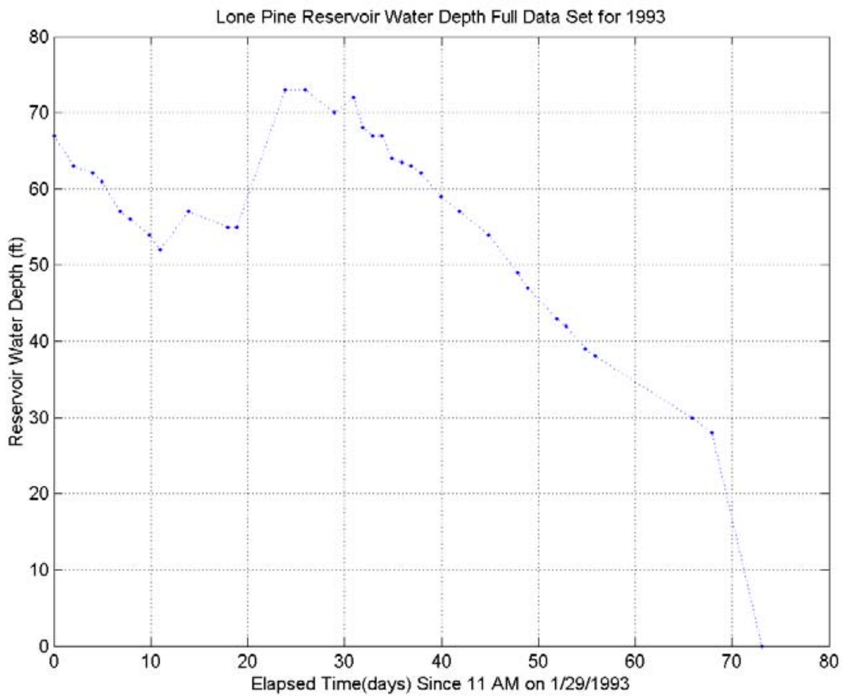
```
%  seepage analysis at Lone Pine reservoir
%
%  Lone Pine reservoir drawdown data from 1993
clear
t(1)=datenum('1/29/93/11:00 am')
h(1)=64
t(2)=datenum('1/31/93/12:00 pm')
h(2)=60
t(3)=datenum('2/2/93/11:00 am')
h(3)=59
t(4)=datenum('2/3/93/10:00 am')
h(4)=58
t(5)=datenum('2/5/93/8:00 am')
h(5)=54
t(6)=datenum('2/6/93/8:00 am')
h(6)=53
t(7)=datenum('2/8/93/8:00 am')
h(7)=51
t(8)=datenum('2/9/93/10:00 am')
h(8)=49
t(9)=datenum('2/12/93/9:00 am')
h(9)=54
t(10)=datenum('2/16/93/8:30 am')
h(10)=52
t(11)=datenum('2/17/93/8:00 am')
h(11)=52
t(12)=datenum('2/22/93/8:00 am')
h(12)=70
t(13)=datenum('2/24/93/9:00 am')
h(13)=70
t(14)=datenum('2/27/93/9:00 am')
h(14)=67
t(15)=datenum('3/1/93/9:00 am')
h(15)=69
t(16)=datenum('3/2/93/8:00 am')
h(16)=65
t(17)=datenum('3/3/93/8:00 am')
h(17)=64
t(18)=datenum('3/4/93/7:30 am')
h(18)=64
t(19)=datenum('3/5/93/7:20 am')
h(19)=61
t(20)=datenum('3/6/93/8:20 am')
h(20)=60.5
t(21)=datenum('3/7/93/8:00 am')
h(21)=60
t(22)=datenum('3/8/93/8:00 am')
h(22)=59
t(23)=datenum('3/10/93/9:00 am')
h(23)=56
t(24)=datenum('3/12/93/8:00 am')
h(24)=54
t(25)=datenum('3/15/93/8:00 am')
h(25)=51
t(26)=datenum('3/18/93/8:00 am')
h(26)=46
t(27)=datenum('3/19/93/8:00 am')
h(27)=44
t(28)=datenum('3/22/93/8:00 am')
h(28)=40
t(29)=datenum('3/23/93/8:00 am')
h(29)=39
t(30)=datenum('3/25/93/8:00 am')
h(30)=36
t(31)=datenum('3/26/93/8:00 am')
h(31)=35
t(32)=datenum('4/5/93/8:00 am')
```

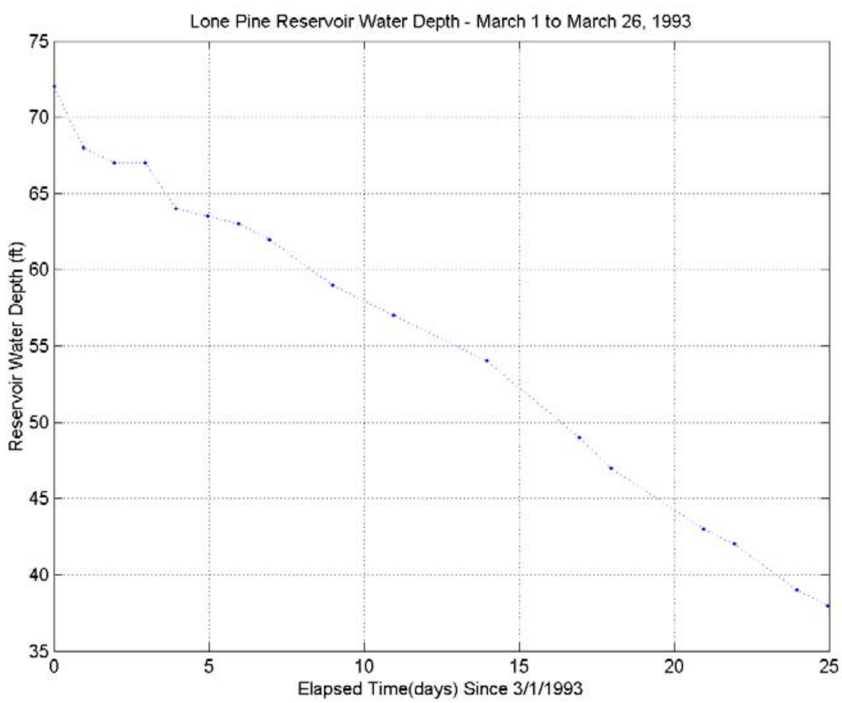
```
h(32)=27
t(33)=datenum('4/7/93/8:00 am')
h(33)=25
t(34)=datenum('4/12/93/12:00 pm')
h(34)=0
%  end of stage data
%
%  apply corrections for the fact that the datum for the above elevation data is -3 ft and is at the inlet invert
%  i.e., set the datum to be 0 at the invert at the inlet
h=h+3
h(34)=0
%  plot the full data set
plot(t(1:34)-t(1),h(1:34),':.'); grid on
xlabel('Elapsed Time(days) Since 11 AM on 1/29/1993')
ylabel('Reservoir Water Depth (ft)')
title('Lone Pine Reservoir Water Depth Full Data Set for 1993')
pause
%  create a partial data set that goes from March 1 thru March 26
tmod=t(15:31)
hmod=h(15:31)
%  plot the partial data set
plot(tmod-tmod(1),hmod,':.'); grid on
xlabel('Elapsed Time(days) Since 3/1/1993')
ylabel('Reservoir Water Depth (ft)')
title('Lone Pine Reservoir Water Depth - March 1 to March 26, 1993')
pause
%  linearize the reservoir stage versus time data set, using two points
tlin=[tmod(1),tmod(17)]
hlin=[hmod(1),hmod(17)]
%  develop vectors of mid-day times and corresponding stages from March 1 to April 12, 1993 using interpolation
tint(1)=datenum('3/1/93/12:00 pm')
for i=2:25
   tint(i)=tint(i-1)+1;
end
z_int=interp1(tlin,hlin,tint)
%  plot interpolated stages
plot(tint-tint(1),z_int,':.'); grid on
xlabel('Elapsed Time (Days) Since 3/1/1993')
ylabel('Reservoir Water Depth (ft)')
title('Lone Pine Reservoir Water Depth - Interpolated & Linearized - March 1 to March 26, 1993')
pause
% load reservoir capacity and pool area data - use depth rather than level (used for curve on p. D25b in ETL report)
temparray=csvread('Lone Pine Reservoir capacity and area.csv',25,0)
res_volume=temparray(:,1)
res_z=temparray(:,4)
res_area=temparray(:,3)
%  plot reservoir volume versus stage - raw data
plot(res_z,res_volume,':.'); grid on
xlabel('Reservoir Stage (ft)')
ylabel('Capacity (ac-ft)')
title('Lone Pine Reservoir Volume versus Stage - Design Capacity Profile')
pause
%  load inflow data
temparray1=xlsread('1993 Lone Pine Reservoir analysis.xls','Lakeside Data - Subset')
%  shift excel dates (1/1/1900 is zero) to matlab dates (1/1/0000 is zero)and add 0.5 to make it miday
temparray1(:,1)=temparray1(:,1)+datenum('30-Dec-1899')+0.5
%  plot inflow, in cfs (this inflow is Lakeside gauge outflow)
%  FOLLOWING IS AN INFLOW SCALING FACTOR; IT SHOULD BE ONE IF THE GAUGE DATA WERE TAKEN IMMEDIATELY
%  ABOVE LONE PINE; SINCE JACQUES DAM IS IN PINE TOP/LAKESIDE, SCALE BY 1.33
inflowscalefactor=1.33
Q_in=inflowscalefactor*temparray1(:,2)
t_inflow=temparray1(:,1)-temparray1(1,1)
plot(t_inflow,Q_in,':.'); grid on
xlabel('Elapsed Time (Days) Since 3/1/1993')
ylabel('Reservoir Inflow (cfs)')
title('Lone Pine Reservoir Water Inflow - March 1 to April 12, 1993')
pause
tlin=[tint(1),tint(25)]
qlin=[Q_in(1),Q_in(25)]
Q_in=interp1(tlin,qlin,tint)'
```

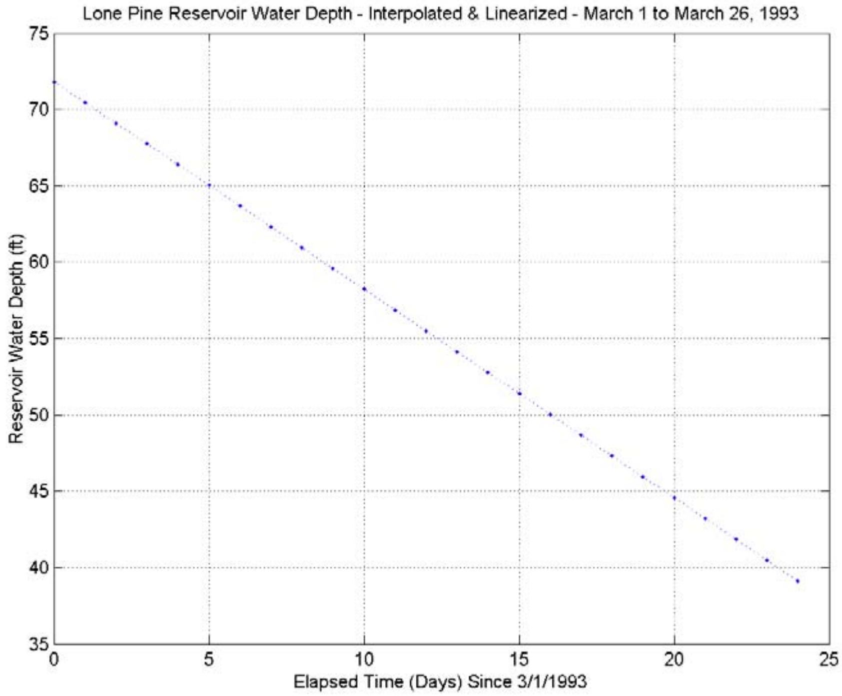
```
plot(tint-tint(1),Q_in,':.'); grid on
xlabel('Elapsed Time (Days) Since 3/1/1993')
ylabel('Reservoir Inflow (cfs)')
title('Lone Pine Reservoir Water Inflow - Linearized - March 1 to March 26, 1993')
pause
% load discharge data
% FOLLOWING IS A RESERVOIR DISCHARGE SCALE FACTOR; IT SHOULD BE 1 IF THE RATING CURVE IS CORRECT
dischargescalefactor=1.
temparray2=xlsread('Lonepineseep.xls','Adopted Rating Table')
Q_out=dischargescalefactor*temparray2(:,3)
z_outflow=temparray2(:,2)
% plot daily pipe discharge, in CFS, versus stage
plot(z_outflow,Q_out,':.'); grid on
xlabel('Stage (ft)')
ylabel('Reservoir Outflow (cfs)')
title('Lone Pine Reservoir Discharge Pipe Rating Curve - RCP (Sq. Edge w/Headwall)')
pause
% determine reservoir capacity versus time, stage
V_int=interp1(res_z,res_volume,z_int,'spline')
plot(z_int,V_int,':.'); grid on
xlabel('Stage (ft)')
ylabel('Reservoir Capacity (ac-ft)')
title('Lone Pine Reservoir Capacity versus Stage')
pause
plot(tint-tint(1),V_int,':.'); grid on
xlabel('Elapsed Time (days) Since 3/1/1993')
ylabel('Stored Water (ac-ft)')
title('Lone Pine Reservoir Storage versus Time')
pause
% 86400 cubic ft per day per cfs; 43560 cubic ft per acre ft; 1.9835 acre-foot/day per cfs
% determine reservoir outflow (acre-ft) versus time
% plot daily pipe discharge, in ac-ft/day, versus time
plot(tint-tint(1),1.9835*interp1(z_outflow,Q_out,z_int),':.'); grid on
xlabel('Elapsed Time (days) Since 3/1/1993')
ylabel('Daily Reservoir Pipe Outflow (acre-ft/day)')
title('Lone Pine Reservoir Daily Pipe Outflow - March 1 to March 26, 1993')
pause
% determine reservoir inflow (acre-ft) versus time
plot(tint-tint(1),1.9835*Q_in,':.'); grid on
xlabel('Elapsed Time (days) Since 3/1/1993')
ylabel('Daily Reservoir Inflow (acre-ft/day)')
title('Lone Pine Reservoir Daily Inflow - March 1 to March 26, 1993')
pause
% determine daily seepage, in acre-ft; the time step is one day
del_t=1
% create a matrix of zeros: 1 row, 25 columns
V_s=zeros(1,25)
% the following factor converts CFS to acre-ft/day
F=del_t*1.9835
V_s(1)=Q_in(1)-interp1(z_outflow,Q_out,z_int(1),'spline')
for i=2:24
   V_s(i)=(1.9835*Q_in(i))-(1.9835*interp1(z_outflow,Q_out,z_int(i),'spline'))+...
      (V_int(i)/del_t)-(V_int(i+1)/del_t)
end
% plot seepage volumetric loss (acre-ft) versus time
plot(tint(2:24)-tint(1),V_s(2:24),':.'); grid on
xlabel('Elapsed Time (days) Since 3/1/1993')
ylabel('Reservoir Daily Seepage Loss (acre-ft)')
title('Lone Pine Reservoir Seepage - March 2 to March 25, 1993')
pause
% plot seepage flow (acre-ft/day) versus stage
plot(z_int(2:24),V_s(2:24),':.'); grid on
axis([0 75 0 400])
xlabel('Reservoir Stage (ft)')
ylabel('Reservoir Seepage Loss (acre-ft/day)')
title('Lone Pine Reservoir Seepage Loss versus Stage')
pause
% plot seepage flow (acre-ft/day) versus elevation
plot((925+z_int(2:24)),V_s(2:24),':.'); grid minor
axis([925 1000 0 400])
```

```
xlabel('Reservoir Water Surface Elevation (ft)')
ylabel('Reservoir Seepage Loss (acre-ft/day)')
title('Lone Pine Reservoir Seepage Loss versus Stage')
%  plot seepage flow (cfs) versus elevation
plot((925+z_int(2:24)),(1/1.9835)*V_s(2:24),':.'); grid minor
axis([925 1000 0 200])
xlabel('Reservoir Water Surface Elevation (ft)')
ylabel('Reservoir Seepage Loss (cfs)')
title('Lone Pine Reservoir Seepage Loss versus Stage')
pause
%  plot seepage flow (cfs) versus elevation with extrapolated values
z_int(25:30)=[35 30 25 20 10 0]
V_s(25:30)=[150 100 40 16 4 0]
plot((925+z_int(2:30)),(1/1.9835)*V_s(2:30),':.'); grid minor
axis([925 1000 0 200])
xlabel('Reservoir Water Surface Elevation (ft)')
ylabel('Reservoir Seepage Loss (cfs)')
title('Lone Pine Reservoir Seepage Loss versus Stage - With Extrapolated Values')
pause
%  determine cumulative seepage from March 2 thru March 25, 1993
cum_V_s=sum(V_s(2:24))
%  determine cumulative inflow from March 2 thru March 25, 1993
cum_Q_in=1.9835*sum(Q_in(2:24))
%  determine cumulative outflow from March 2 thru March 25, 1993
cum_Q_out=1.9835*sum(interp1(z_outflow,Q_out,z_int(2:24)))
```

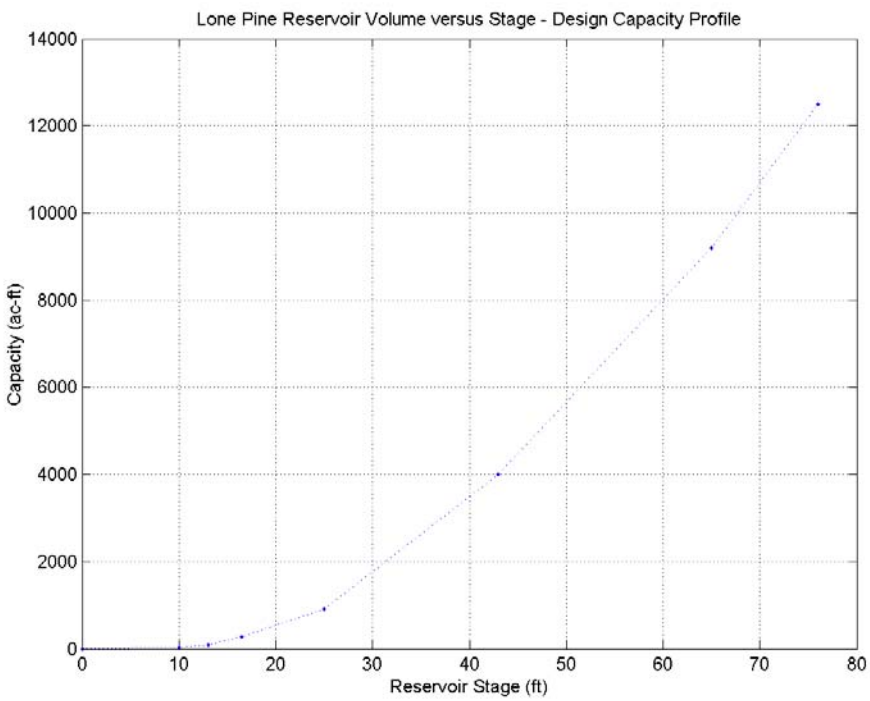
Program Output - Graphs



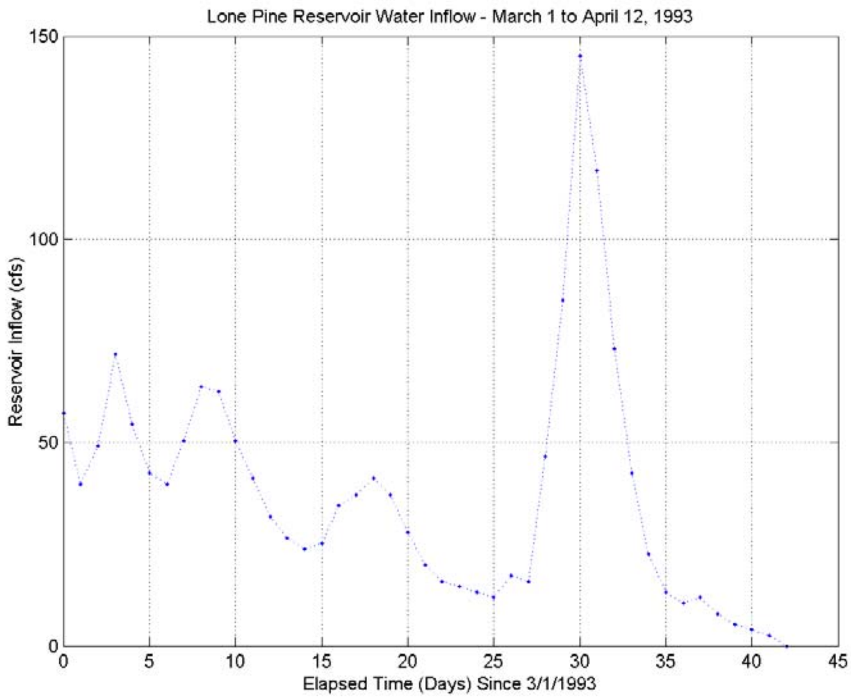


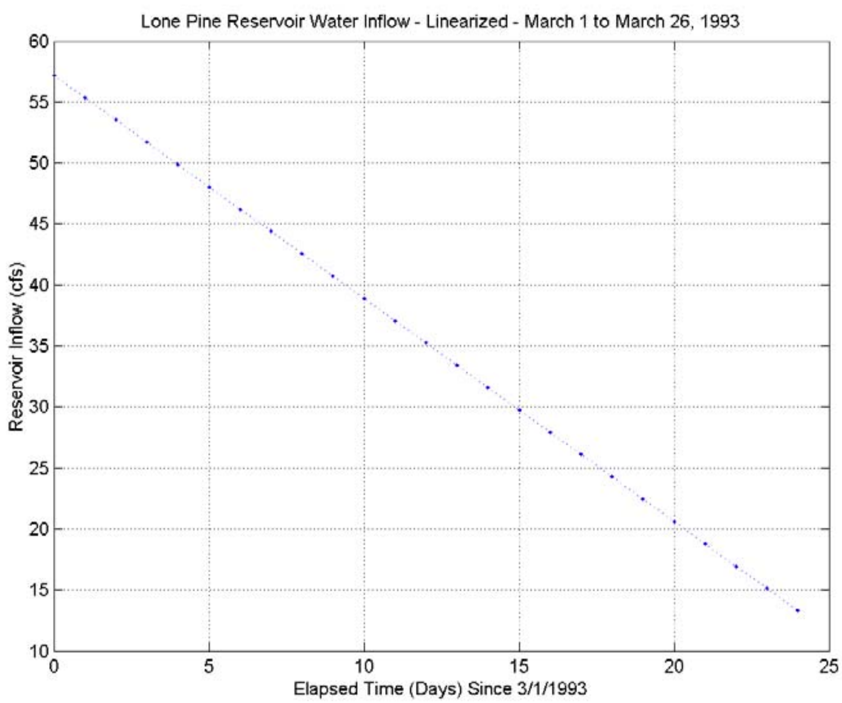


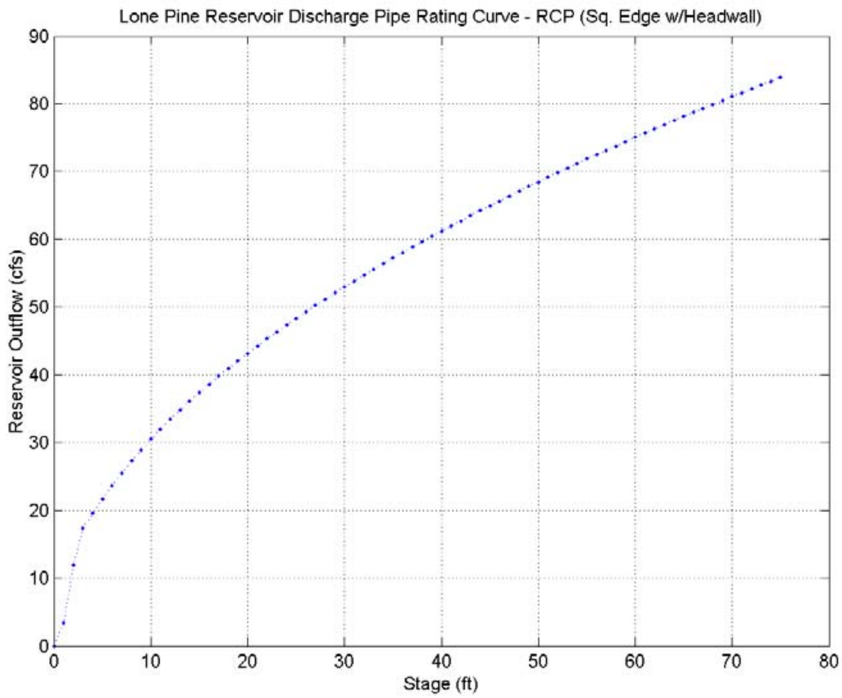
Lone Pine Reservoir Water Depth - Interpolated & Linearized - March 1 to March 26, 1993
Reservoir Water Depth (ft)
Elapsed Time (Days) Since 3/1/1993
75
70
65
60
55
50
45
40
35
0
5
10
15
20
25

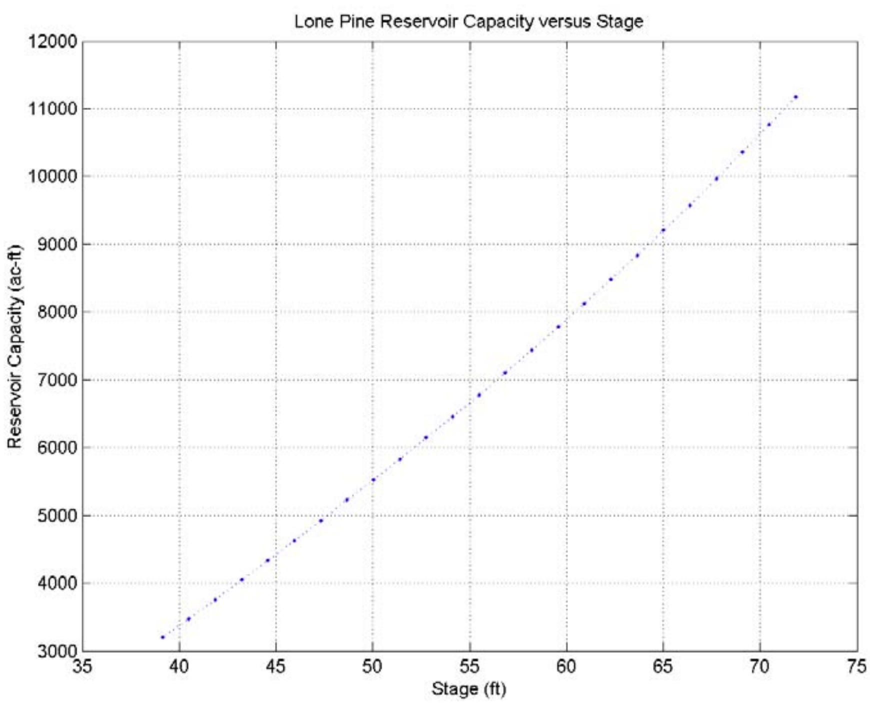


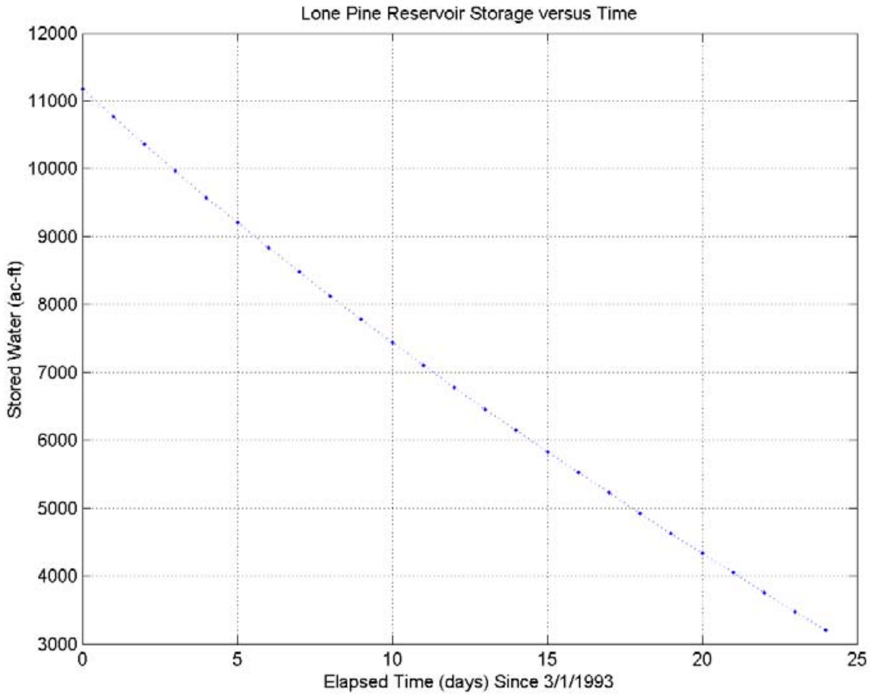
Lone Pine Reservoir Volume versus Stage - Design Capacity Profile
Capacity (ac-ft)
Reservoir Stage (ft)
14000
12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
80


Lone Pine Reservoir Water Inflow - March 1 to April 12, 1993
Reservoir Inflow (cfs)
Elapsed Time (Days) Since 3/1/1993
0
50
100
150
0
5
10
15
20
25
30
35
40
45

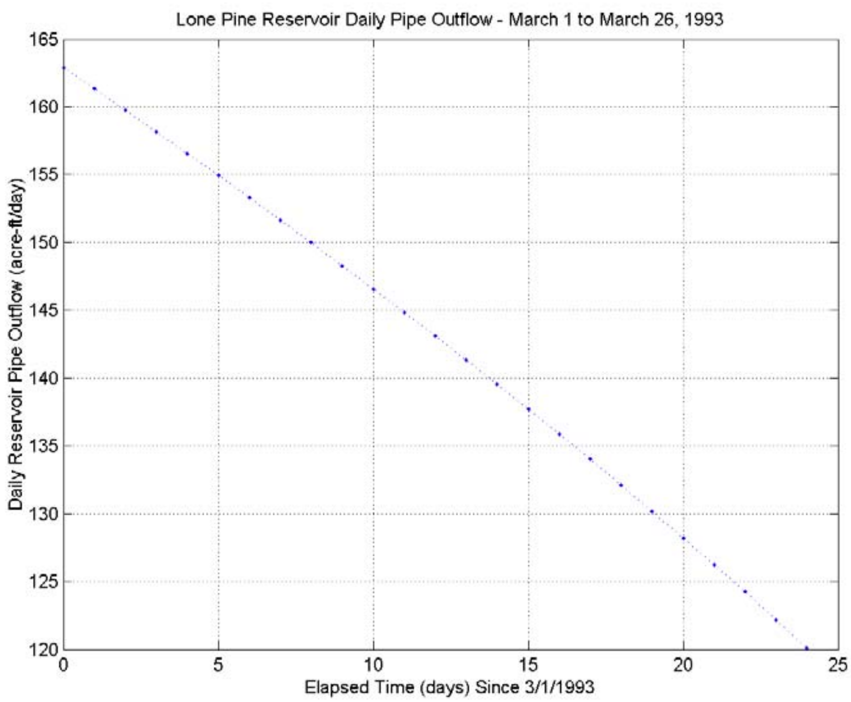

Lone Pine Reservoir Water Inflow - Linearized - March 1 to March 26, 1993
Reservoir Inflow (cfs)
Elapsed Time (Days) Since 3/1/1993
10
15
20
25
30
35
40
45
50
55
60
0
5
10
15
20
25


Lone Pine Reservoir Discharge Pipe Rating Curve - RCP (Sq. Edge w/Headwall)
Reservoir Outflow (cfs)
Stage (ft)
0
10
20
30
40
50
60
70
80
90

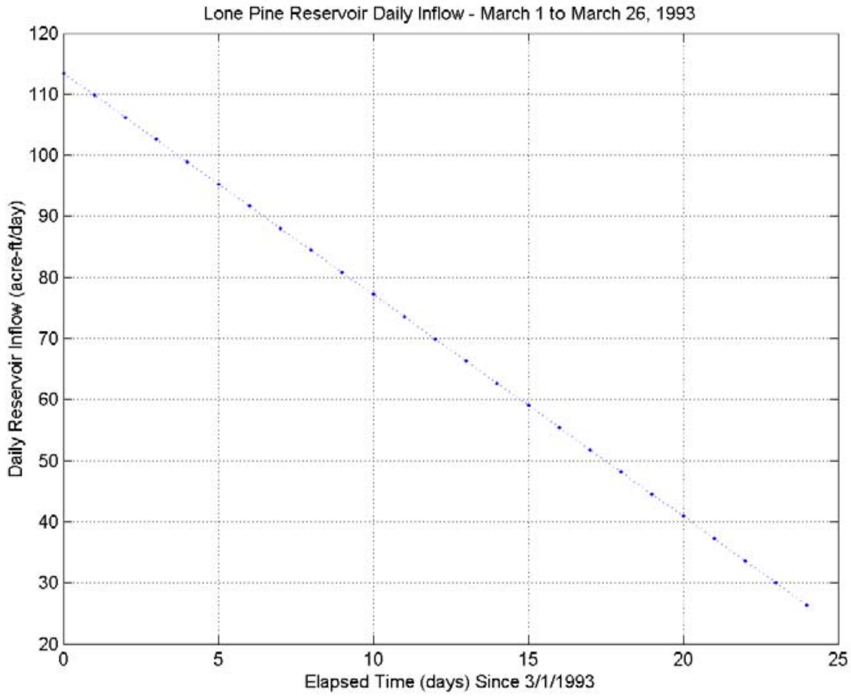

Lone Pine Reservoir Capacity versus Stage
Reservoir Capacity (ac-ft)
Stage (ft)
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
35
40
45
50
55
60
65
70
75

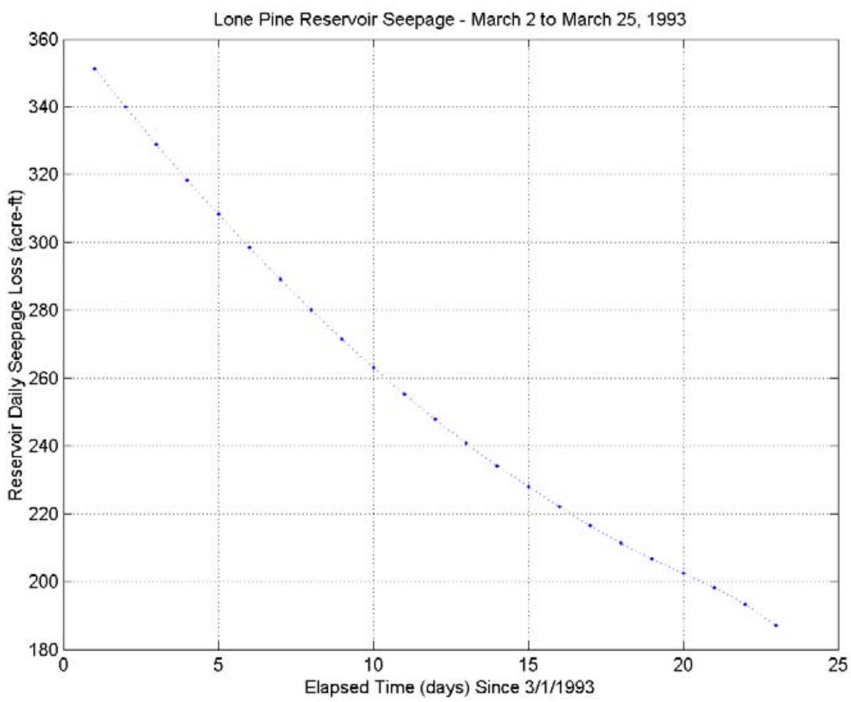


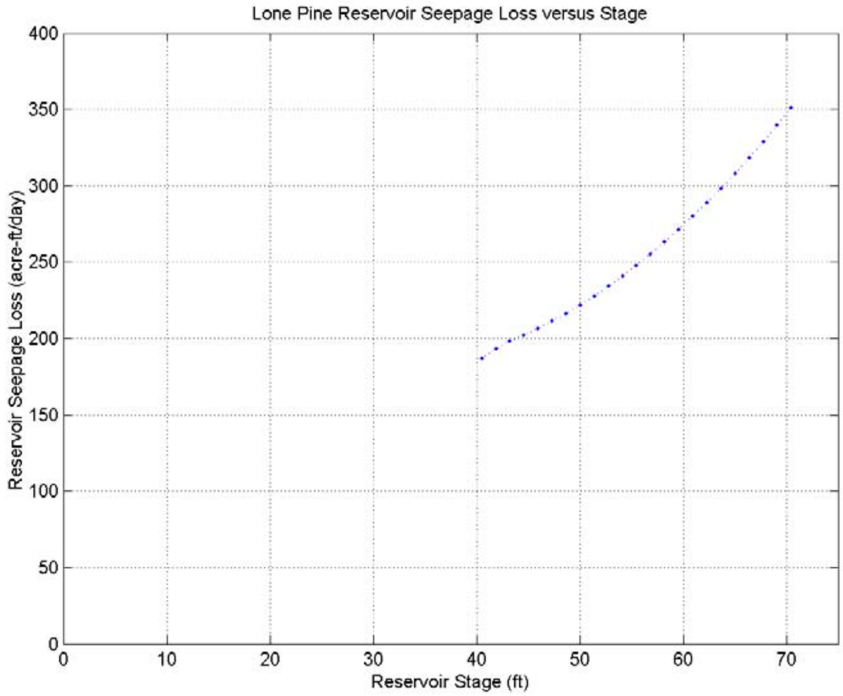
Lone Pine Reservoir Storage versus Time
Stored Water (ac-ft)
Elapsed Time (days) Since 3/1/1993

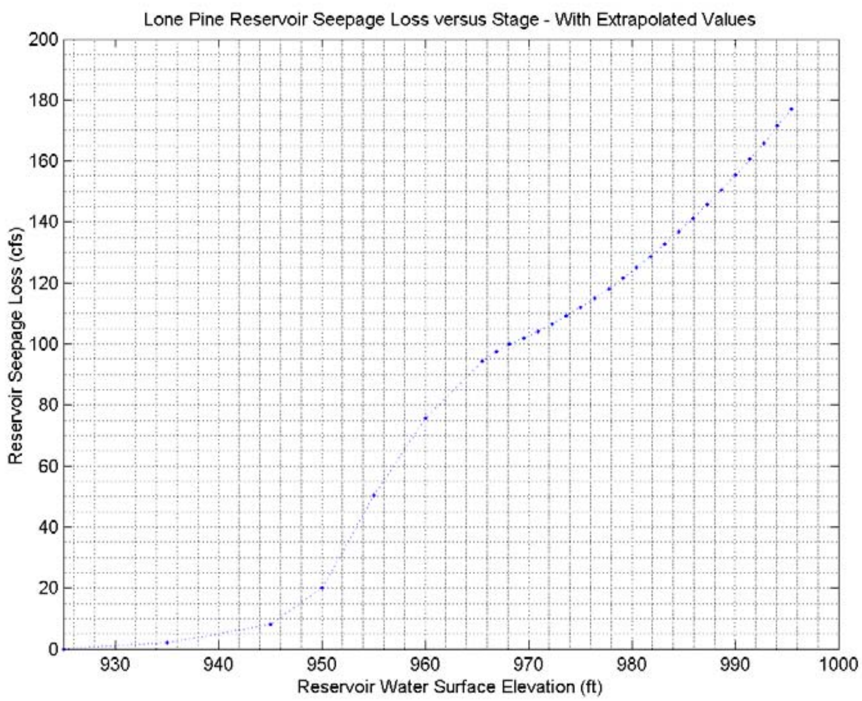


Lone Pine Reservoir Daily Pipe Outflow - March 1 to March 26, 1993
Daily Reservoir Pipe Outflow (acre-ft/day)
Elapsed Time (days) Since 3/1/1993


Lone Pine Reservoir Daily Inflow - March 1 to March 26, 1993
Daily Reservoir Inflow (acre-ft/day)
Elapsed Time (days) Since 3/1/1993
120
110
100
90
80
70
60
50
40
30
20
0
5
10
15
20
25


Lone Pine Reservoir Seepage - March 2 to March 25, 1993
Reservoir Daily Seepage Loss (acre-ft)
Elapsed Time (days) Since 3/1/1993
360
340
320
300
280
260
240
220
200
180
0
5
10
15
20
25

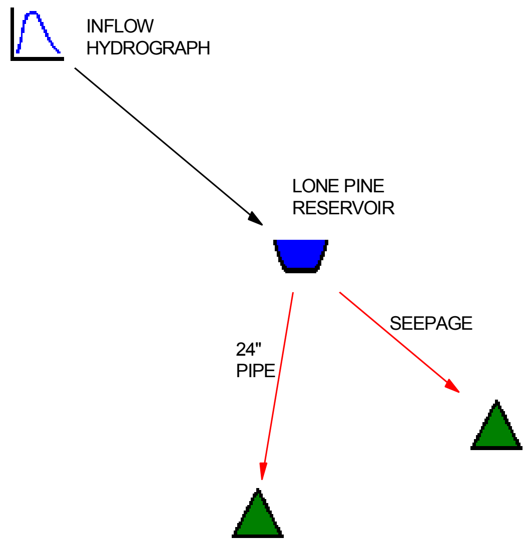

Lone Pine Reservoir Seepage Loss versus Stage
Reservoir Seepage Loss (acre-ft/day)
Reservoir Stage (ft)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70


Lone Pine Reservoir Seepage Loss versus Stage - With Extrapolated Values
Reservoir Seepage Loss (cfs)
Reservoir Water Surface Elevation (ft)
0
20
40
60
80
100
120
140
160
180
200
930
940
950
960
970
980
990
1000

Appendix 3

Numerical Simulation of Routing of Average Annual Flow Through Lone Pine: Supporting Documentation

Layout



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Job File: h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW
Rain Dir: h:\EGR38BA\recharge\pondpack data\

                       ==========================
                               JOB TITLE
                       ==========================

   Project Date: 10/10/2002
   Project Engineer:
      Project Title: Watershed
   Project Comments:
   project as edited by cms 10/10/2002
```

```
Type.... Master Network Summary                               Page 1.01
Name.... Watershed
File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW
```

MASTER DESIGN STORM SUMMARY

Hydrograph Queue Only Network

MASTER NETWORK SUMMARY
SCS Unit Hydrograph Method
Hydrograph File Import Option Used For 1 node(s)

(*Node=Outfall; +Node=Diversion;)
(Trun= HYG Truncation: Blank=None; L=Left; R=Rt; LR=Left&Rt)

Node ID		Type	Return Event	HYG Vol ac-ft	Trun	Qpeak hrs	Qpeak cfs	Max WSEL ft	Max Pond Storage ac-ft
LP-RES		HYG		10022.780		1608.0000	202.62		
LP-RES	IN	POND		10022.780		1608.0000	202.62		
+LP-RES	OUT	POND		10022.780		1824.0000	109.81	956.29	1945.023
*PIPE		JCT		8093.225		1824.0000	54.12		
*SEEPAGE		JCT		2443.185		1824.0000	55.70		

```
   Type.... Executive Summary (Nodes)                               Page 2.01
   Name.... Watershed                                         Event: 1968d yr
   File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW
   Storm... 1968d   Tag: 1968d

                          NETWORK SUMMARY -- NODES
        (Trun.= HYG Truncation: Blank=None; L=Left; R=Rt; LR=Left & Rt)

                                    HYG Vol       Qpeak      Qpeak     Max WSEL
        Node ID           Type      ac-ft  Trun.  hrs         cfs         ft
       -----------------  ----    ---------- -- ---------   --------   -------
        LP-RES            HYG     10022.780    1608.0000     202.62
        LP-RES        IN  POND    10022.780    1608.0000     202.62
Divert  LP-RES       OUT  POND    10022.780    1824.0000     109.81     956.29
Outfall PIPE              JCT      8093.225    1824.0000      54.12
Outfall SEEPAGE           JCT      2443.185    1824.0000      55.70


   Type.... Executive Summary (Links)
   Name.... Watershed                                         Event: 1968d yr
   File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW
   Storm... 1968d   Tag: 1968d

                         NETWORK SUMMARY -- LINKS
        (UN=Upstream Node; DL=DNstream End of Link; DN=DNstream Node)
        (Trun.= HYG Truncation: Blank=None; L=Left; R=Rt; LR=Left & Rt)

                                HYG Vol      Peak Time  Peak Q
 Link ID          Type          ac-ft  Trun.   hrs       cfs     End Points
 ---------------- ----       ----------- --- -------   --------  --------------
 24" PIPE         PONDrt UN   10022.780    1608.0000
                                                         202.62  LP-RES       IN
 24" PIPE                     10022.780    1824.0000
                                                         109.81  LP-RES       OUT
                  DIVERT DL    8093.225    1824.0000
                                                          54.12
                         DN    8093.225    1824.0000
                                                          54.12  PIPE

 LP-RES           ADD    UN   10022.780    1608.0000
                                                         202.62  LP-RES
                         DL   10022.780    1608.0000
                                                         202.62
                         DN   10022.780    1608.0000
                                                         202.62  LP-RES       IN

 SEEPAGE          PONDrt UN   10022.780    1608.0000
                                                         202.62  LP-RES       IN
 SEEPAGE                      10022.780    1824.0000
                                                         109.81  LP-RES       OUT
                  DIVERT DL    2443.185    1824.0000
                                                          55.70
                         DN    2443.185    1824.0000
                                                          55.70  SEEPAGE
   Type.... Network Calcs Sequence                                  Page 2.02
   Name.... Watershed                                         Event: 1968d yr
```

```
Type.... Read HYG                                              Page 3.01
Name.... LP-RES             Tag: 1968d                    Event: 1968d yr
File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW
Storm... Tag: 1968d


            HYG file =
            HYG ID   = 1968X1.33
            HYG Tag  = 1968a
            -----------------------------------
            Peak Discharge =      202.62 cfs
            Time to Peak   =    1608.0000 hrs
            HYG Volume     =    10022.780 ac-ft
            -----------------------------------

                          HYDROGRAPH ORDINATES (cfs)
    Time  |               Output Time increment = 24.0000 hrs
    hrs   |    Time on left represents time for first value in each row.
 ---------|-------------------------------------------------------------
     .0000 |       1.33        1.33        1.33        1.33        1.33
  120.0000 |       1.33        1.33        1.33        1.33        1.33
  240.0000 |       1.47        1.47        1.47        1.47        1.47
  360.0000 |       1.47        1.47        1.47        1.47        1.47
  480.0000 |       1.47        1.47        1.47        1.47        1.47
  600.0000 |       1.33        1.33        1.33        1.33        1.33
  720.0000 |       1.33        1.33        1.33        1.33        1.33
  840.0000 |       1.33        1.33        1.33        1.33        1.47
  960.0000 |       1.47        1.47        1.47        1.60        1.60
 1080.0000 |       1.60        1.60        1.87        2.13        2.13
 1200.0000 |       2.13        2.13        2.13        2.13        2.13
 1320.0000 |       2.40        2.40        2.40        2.40       16.00
 1440.0000 |     122.64      109.31       82.65       82.65       69.32
 1560.0000 |      62.65      162.63      202.62      162.63      122.64
 1680.0000 |     109.31      122.64      162.63      202.62      182.62
 1800.0000 |     169.29      122.64       55.99       35.99       29.33
 1920.0000 |      22.66       22.66       16.00        9.33       55.99
 2040.0000 |      62.65       69.32       75.98       75.98       75.98
 2160.0000 |      62.65       53.32       69.32       55.99       49.32
 2280.0000 |      35.99       29.33       29.33       22.66       16.00
 2400.0000 |      16.00       16.00       16.00       16.00       16.00
 2520.0000 |      13.33        9.33        9.33        9.33        9.33
 2640.0000 |       2.80        2.80        2.80        9.33        9.33
 2760.0000 |      16.00       16.00        9.33        9.33        2.80
 2880.0000 |       2.80        2.80        3.87        4.80        5.87
 3000.0000 |       6.93        7.06        7.06        7.06        7.06
 3120.0000 |       7.06        7.06        7.06        7.73        9.60
 3240.0000 |       9.86       10.13       10.13       10.13       10.13
 3360.0000 |      10.13       10.13       10.13       10.13       10.13
 3480.0000 |      10.13       10.13       10.13       10.13       10.40
 3600.0000 |      10.40       10.40       10.00        9.86        9.86
 3720.0000 |       9.86        9.86        9.86        9.86        9.86
 3840.0000 |       9.86        9.86        9.86        9.86        9.86
```

```
Type.... Read HYG                                                   Page 3.02
Name.... LP-RES             Tag: 1968d                        Event: 1968d yr
File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW
Storm... Tag: 1968d
```

HYDROGRAPH ORDINATES (cfs)
Output Time increment = 24.0000 hrs
Time on left represents time for first value in each row.

Time hrs					
3960.0000	9.86	9.86	9.86	9.86	9.86
4080.0000	9.73	9.60	9.60	9.60	9.86
4200.0000	10.26	10.26	10.66	10.80	10.80
4320.0000	11.06	11.33	11.33	11.33	11.33
4440.0000	11.33	11.46	11.33	10.80	10.80
4560.0000	10.80	10.80	10.80	10.80	10.80
4680.0000	10.80	10.80	11.20	11.33	11.33
4800.0000	11.33	11.33	11.33	11.33	11.33
4920.0000	11.20	11.20	10.40	10.13	9.20
5040.0000	6.93	6.93	3.87	2.80	2.80
5160.0000	2.80	2.80	2.80	2.67	2.67
5280.0000	2.67	2.67	2.67	2.67	2.53
5400.0000	2.40	2.40	4.53	6.80	8.00
5520.0000	8.66	8.66	8.93	9.06	9.06
5640.0000	9.06	9.06	9.33	9.60	9.73
5760.0000	9.73	9.73	9.73	9.73	9.73
5880.0000	9.73	9.60	9.60	8.53	7.86
6000.0000	7.86	7.86	7.86	7.73	7.73
6120.0000	2.80	4.40	8.00	9.20	9.20
6240.0000	9.20	9.20	9.20	9.20	9.20
6360.0000	9.20	9.20	9.20	9.20	9.20
6480.0000	9.20	9.20	9.20	8.00	7.46
6600.0000	7.46	7.46	5.07	3.73	2.80
6720.0000	1.05	1.05	1.05	1.05	1.05
6840.0000	1.05	1.05	1.05	1.05	1.05
6960.0000	1.05	1.05	1.05	1.05	1.05
7080.0000	1.05	1.05	1.05	1.05	1.05
7200.0000	1.05	1.05	3.07	4.13	4.27
7320.0000	2.13	1.19	1.19	1.19	1.19
7440.0000	1.19	1.19	1.19	1.19	1.19
7560.0000	1.19	1.20	1.19	1.19	1.19
7680.0000	1.19	1.19	1.19	1.19	1.19
7800.0000	1.19	1.19	1.19	1.19	1.19
7920.0000	1.19	1.19	1.19	1.19	1.19
8040.0000	1.19	1.19	1.19	1.19	1.19
8160.0000	1.19	1.19	1.19	.57	.00
8280.0000	.00	.00	.00	.00	.00
8400.0000	.00	.00	.00	.00	.00
8520.0000	.00	.00	.00	.00	.00
8640.0000	.00	.00	.00	.00	.00
8760.0000	.00				

```
Type.... Vol: Elev-Volume                                     Page 4.01
Name.... LP-RES

File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW
```

USER DEFINED VOLUME RATING TABLE

Elevation (ft)	Volume (ac-ft)
925.00	.000
935.00	40.000
938.00	100.000
941.00	285.000
950.00	840.000
968.00	4000.000
990.00	9143.000
1000.00	12540.000

```
Type.... Outlet Input Data                                      Page 5.01
Name.... 24" PIPE

File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW


                   REQUESTED POND WS ELEVATIONS:

                     Min. Elev.=    925.00 ft
                     Increment =      1.00 ft
                     Max. Elev.=   1000.00 ft


           **********************************************
                          OUTLET CONNECTIVITY
           **********************************************

            ---> Forward Flow Only (UpStream to DnStream)
           <---  Reverse Flow Only (DnStream to UpStream)
           <---> Forward and Reverse Both Allowed

       Structure        No.        Outfall    E1, ft     E2, ft
   -----------------    ----        -------  ---------  ---------
   Culvert-Circular           --->    TW     925.000   1000.000
   TW SETUP, DS Channel
```

```
Type.... Outlet Input Data                                    Page 5.02
Name.... 24" PIPE

File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW

              OUTLET STRUCTURE INPUT DATA

              Structure ID      =
              Structure Type    = Culvert-Circular
              ------------------------------------
              No. Barrels       =        1
              Barrel Diameter   =    2.0000 ft
              Upstream Invert   =    925.00 ft
              Dnstream Invert   =    923.17 ft
              Horiz. Length     =    423.00 ft
              Barrel Length     =    423.00 ft
              Barrel Slope      =    .00433 ft/ft

              OUTLET CONTROL DATA...
              Mannings n        =     .0130
              Ke                =     .5000  (forward entrance loss)
              Kb                =   .012411  (per ft of full flow)
              Kr                =     .5000  (reverse entrance loss)
              HW Convergence    =      .001  +/- ft

              INLET CONTROL DATA...
              Equation form     =        1
              Inlet Control K   =     .0098
              Inlet Control M   =    2.0000
              Inlet Control c   =    .03980
              Inlet Control Y   =     .6700
              T1 ratio (HW/D)   =     1.158
              T2 ratio (HW/D)   =     1.305
              Slope Factor      =     -.500

 Use unsubmerged inlet control Form 1 equ. below T1 elev.
 Use   submerged inlet control Form 1 equ. above T2 elev.

 In transition zone between unsubmerged and submerged inlet control,
 interpolate between flows at T1 & T2...
 At T1 Elev =    927.32 ft  --->  Flow =     15.55 cfs
 At T2 Elev =    927.61 ft  --->  Flow =     17.77 cfs

              Structure ID      = TW
              Structure Type    = TW SETUP, DS Channel
              ------------------------------------
              FREE OUTFALL CONDITIONS SPECIFIED

              CONVERGENCE TOLERANCES...
              Maximum Iterations=    30
              Min. TW tolerance =    .01 ft
              Max. TW tolerance =    .01 ft
              Min. HW tolerance =    .01 ft
              Max. HW tolerance =    .01 ft
              Min.  Q tolerance =    .10 cfs
              Max.  Q tolerance =    .10 cfs
```

```
Type.... Individual Outlet Curves                              Page 5.03
Name.... 24" PIPE

File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW


               RATING TABLE FOR ONE OUTLET TYPE

               Structure ID  =   (Culvert-Circular)
               --------------------------------------
               Mannings open channel maximum capacity: 16.01 cfs
               Upstream  ID  =    (Pond Water Surface)
               DNstream  ID  = TW (Pond Outfall)


WS Elev,Device Q    Tail Water              Notes
----------------  ---------------  --------------------------
WS Elev.    Q      TW Elev Converge
  ft       cfs        ft    +/-ft   Computation Messages
--------  -------  --------  -----  --------------------------
 925.00       .00   Free Outfall
                Upstream HW & DNstream TW < Inv.El
 926.00      3.43   Free Outfall
                CRIT.DEPTH CONTROL  Vh= .235ft  Dcr= .648ft  H.JUMP IN PIPE
 927.00     11.91   Free Outfall
                BACKWATER CONTROL.. Vh= .430ft  hwDi= 1.354ft  Lbw= 423.0ft
 928.00     17.38   Free Outfall
                FULL FLOW...Lfull=181.20ft  Vh=.476ft  HL=1.784ft
 929.00     19.57   Free Outfall
                FULL FLOW...Lfull=346.53ft  Vh=.603ft  HL=3.498ft
 930.00     21.69   Free Outfall
                FULL FLOW...Lfull=387.53ft  Vh=.741ft  HL=4.676ft
 931.00     23.68   Free Outfall
                FULL FLOW...Lfull=403.54ft  Vh=.883ft  HL=5.745ft
 932.00     25.53   Free Outfall
                FULL FLOW...Lfull=411.47ft  Vh=1.026ft  HL=6.780ft
 933.00     27.28   Free Outfall
                FULL FLOW...Lfull=415.28ft  Vh=1.172ft  HL=7.797ft
 934.00     28.93   Free Outfall
                FULL FLOW...Lfull=417.74ft  Vh=1.318ft  HL=8.808ft
 935.00     30.49   Free Outfall
                FULL FLOW...Lfull=419.44ft  Vh=1.464ft  HL=9.814ft
 936.00     31.98   Free Outfall
                FULL FLOW...Lfull=420.48ft  Vh=1.610ft  HL=10.819ft
 937.00     33.41   Free Outfall
                FULL FLOW...Lfull=420.95ft  Vh=1.758ft  HL=11.821ft
 938.00     34.78   Free Outfall
                FULL FLOW...Lfull=421.78ft  Vh=1.904ft  HL=12.824ft
 939.00     36.10   Free Outfall
                FULL FLOW...Lfull=421.90ft  Vh=2.052ft  HL=13.825ft
 940.00     37.39   Free Outfall
                FULL FLOW...Lfull=421.92ft  Vh=2.201ft  HL=14.828ft
 941.00     38.62   Free Outfall
                FULL FLOW...Lfull=422.19ft  Vh=2.348ft  HL=15.827ft
```

```
Type.... Individual Outlet Curves                                Page 5.04
 Name.... 24" PIPE

 File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW


                RATING TABLE FOR ONE OUTLET TYPE

                Structure ID  =   (Culvert-Circular)
                --------------------------------------
                Mannings open channel maximum capacity: 16.01 cfs
                Upstream  ID  =    (Pond Water Surface)
                DNstream  ID  = TW (Pond Outfall)


 WS Elev,Device Q    Tail Water              Notes
 ----------------  ---------------  --------------------------
 WS Elev.    Q      TW Elev Converge
   ft       cfs        ft    +/-ft   Computation Messages
--------  -------  --------  -----  --------------------------
 942.00     39.81   Free Outfall
                 FULL FLOW...Lfull=422.34ft  Vh=2.496ft  HL=16.826ft
 943.00     40.98   Free Outfall
                 FULL FLOW...Lfull=422.50ft  Vh=2.644ft  HL=17.828ft
 944.00     42.11   Free Outfall
                 FULL FLOW...Lfull=422.56ft  Vh=2.792ft  HL=18.828ft
 945.00     43.20   Free Outfall
                 FULL FLOW...Lfull=422.74ft  Vh=2.939ft  HL=19.828ft
 946.00     44.28   Free Outfall
                 FULL FLOW...Lfull=422.75ft  Vh=3.087ft  HL=20.830ft
 947.00     45.33   Free Outfall
                 FULL FLOW...Lfull=422.77ft  Vh=3.235ft  HL=21.828ft
 948.00     46.36   Free Outfall
                 FULL FLOW...Lfull=422.78ft  Vh=3.384ft  HL=22.829ft
 949.00     47.36   Free Outfall
                 FULL FLOW...Lfull=422.79ft  Vh=3.532ft  HL=23.830ft
 950.00     48.34   Free Outfall
                 FULL FLOW...Lfull=422.83ft  Vh=3.680ft  HL=24.830ft
 951.00     49.31   Free Outfall
                 FULL FLOW...Lfull=422.83ft  Vh=3.828ft  HL=25.829ft
 952.00     50.25   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=3.975ft  HL=26.829ft
 953.00     51.17   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=4.124ft  HL=27.829ft
 954.00     52.09   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=4.272ft  HL=28.830ft
 955.00     52.98   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=4.420ft  HL=29.830ft
 956.00     53.86   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=4.568ft  HL=30.830ft
 957.00     54.73   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=4.716ft  HL=31.830ft
 958.00     55.58   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=4.864ft  HL=32.829ft
```

```
Type.... Individual Outlet Curves                              Page 5.05
Name.... 24" PIPE

File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW


               RATING TABLE FOR ONE OUTLET TYPE

               Structure ID  =   (Culvert-Circular)
               --------------------------------------
               Mannings open channel maximum capacity: 16.01 cfs
               Upstream  ID  =    (Pond Water Surface)
               DNstream  ID  = TW (Pond Outfall)


WS Elev,Device Q    Tail Water              Notes
----------------  ---------------  --------------------------
WS Elev.    Q      TW Elev Converge
  ft       cfs        ft    +/-ft   Computation Messages
--------  -------  --------  -----  --------------------------
 959.00     56.42   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=5.013ft  HL=33.830ft
 960.00     57.25   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=5.161ft  HL=34.829ft
 961.00     58.07   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=5.309ft  HL=35.829ft
 962.00     58.87   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=5.457ft  HL=36.830ft
 963.00     59.67   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=5.605ft  HL=37.830ft
 964.00     60.45   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=5.754ft  HL=38.830ft
 965.00     61.22   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=5.902ft  HL=39.829ft
 966.00     61.99   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=6.050ft  HL=40.829ft
 967.00     62.74   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=6.198ft  HL=41.830ft
 968.00     63.49   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=6.346ft  HL=42.830ft
 969.00     64.22   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=6.495ft  HL=43.830ft
 970.00     64.95   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=6.642ft  HL=44.829ft
 971.00     65.67   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=6.791ft  HL=45.829ft
 972.00     66.38   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=6.939ft  HL=46.829ft
 973.00     67.09   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=7.087ft  HL=47.830ft
 974.00     67.79   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=7.235ft  HL=48.830ft
 975.00     68.48   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=7.384ft  HL=49.830ft
```

```
Type.... Individual Outlet Curves                              Page 5.06
Name.... 24" PIPE

File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW


               RATING TABLE FOR ONE OUTLET TYPE

               Structure ID  =   (Culvert-Circular)
               --------------------------------------
               Mannings open channel maximum capacity: 16.01 cfs
               Upstream  ID  =    (Pond Water Surface)
               DNstream  ID  = TW (Pond Outfall)


WS Elev,Device Q    Tail Water              Notes
----------------  ---------------  --------------------------
WS Elev.    Q      TW Elev Converge
  ft       cfs        ft    +/-ft   Computation Messages
--------  -------  --------  -----  --------------------------
976.00     69.16   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=7.531ft  HL=50.829ft
977.00     69.84   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=7.680ft  HL=51.829ft
978.00     70.51   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=7.828ft  HL=52.829ft
979.00     71.17   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=7.976ft  HL=53.829ft
980.00     71.83   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=8.124ft  HL=54.830ft
981.00     72.48   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=8.272ft  HL=55.830ft
982.00     73.13   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=8.421ft  HL=56.829ft
983.00     73.77   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=8.569ft  HL=57.830ft
984.00     74.40   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=8.717ft  HL=58.829ft
985.00     75.03   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=8.865ft  HL=59.829ft
986.00     75.66   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=9.013ft  HL=60.830ft
987.00     76.28   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=9.161ft  HL=61.829ft
988.00     76.89   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=9.310ft  HL=62.829ft
989.00     77.50   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=9.458ft  HL=63.829ft
990.00     78.11   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=9.606ft  HL=64.830ft
991.00     78.71   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=9.754ft  HL=65.830ft
992.00     79.30   Free Outfall
                FULL FLOW...Lfull=422.92ft  Vh=9.902ft  HL=66.829ft
```

```
Type.... Individual Outlet Curves                              Page 5.07
Name.... 24" PIPE

File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW


               RATING TABLE FOR ONE OUTLET TYPE

               Structure ID  =   (Culvert-Circular)
               --------------------------------------
               Mannings open channel maximum capacity: 16.01 cfs
               Upstream  ID  =    (Pond Water Surface)
               DNstream  ID  = TW (Pond Outfall)


WS Elev,Device Q    Tail Water              Notes
----------------  ---------------  --------------------------
WS Elev.    Q      TW Elev Converge
  ft       cfs        ft    +/-ft   Computation Messages
--------  -------  ---------  -----  --------------------------
 993.00     79.89   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=10.051ft  HL=67.830ft
 994.00     80.48   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=10.199ft  HL=68.830ft
 995.00     81.06   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=10.347ft  HL=69.830ft
 996.00     81.64   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=10.495ft  HL=70.830ft
 997.00     82.22   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=10.643ft  HL=71.830ft
 998.00     82.79   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=10.791ft  HL=72.830ft
 999.00     83.35   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=10.940ft  HL=73.830ft
1000.00     83.91   Free Outfall
                 FULL FLOW...Lfull=422.92ft  Vh=11.088ft  HL=74.829ft
```

```
Type.... Outlet Input Data                                    Page 5.08
Name.... SEEPAGE

File.... h:\EGR38BA\recharge\pondpack data\LONE PINE EVAL.PPW


              OUTLET STRUCTURE INPUT DATA



              Structure ID      =
              Structure Type    = User Defined Table
              ------------------------------------
                              ELEV-FLOW RATING TABLE

                Elev, ft   Flow, cfs
               ---------   ---------
                 925.00         .00
                 935.00        1.00
                 945.00        8.00
                 955.00       50.00
                 965.00       94.00
                 975.00      112.00
                 985.00      138.00
                 995.00      175.00
                1000.00      200.00

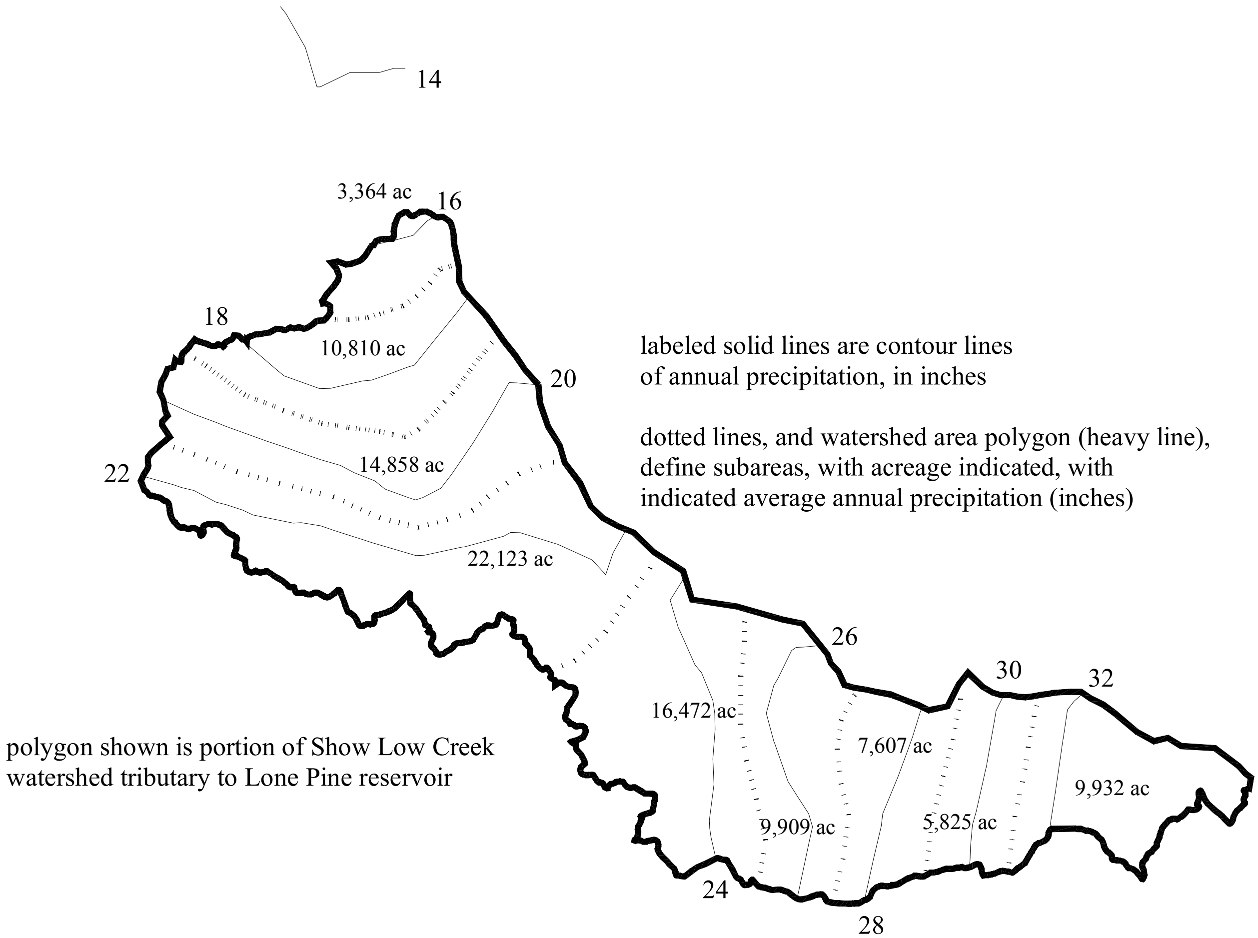


              Structure ID      = TW
              Structure Type    = TW SETUP, DS Channel
              ------------------------------------
              FREE OUTFALL CONDITIONS SPECIFIED

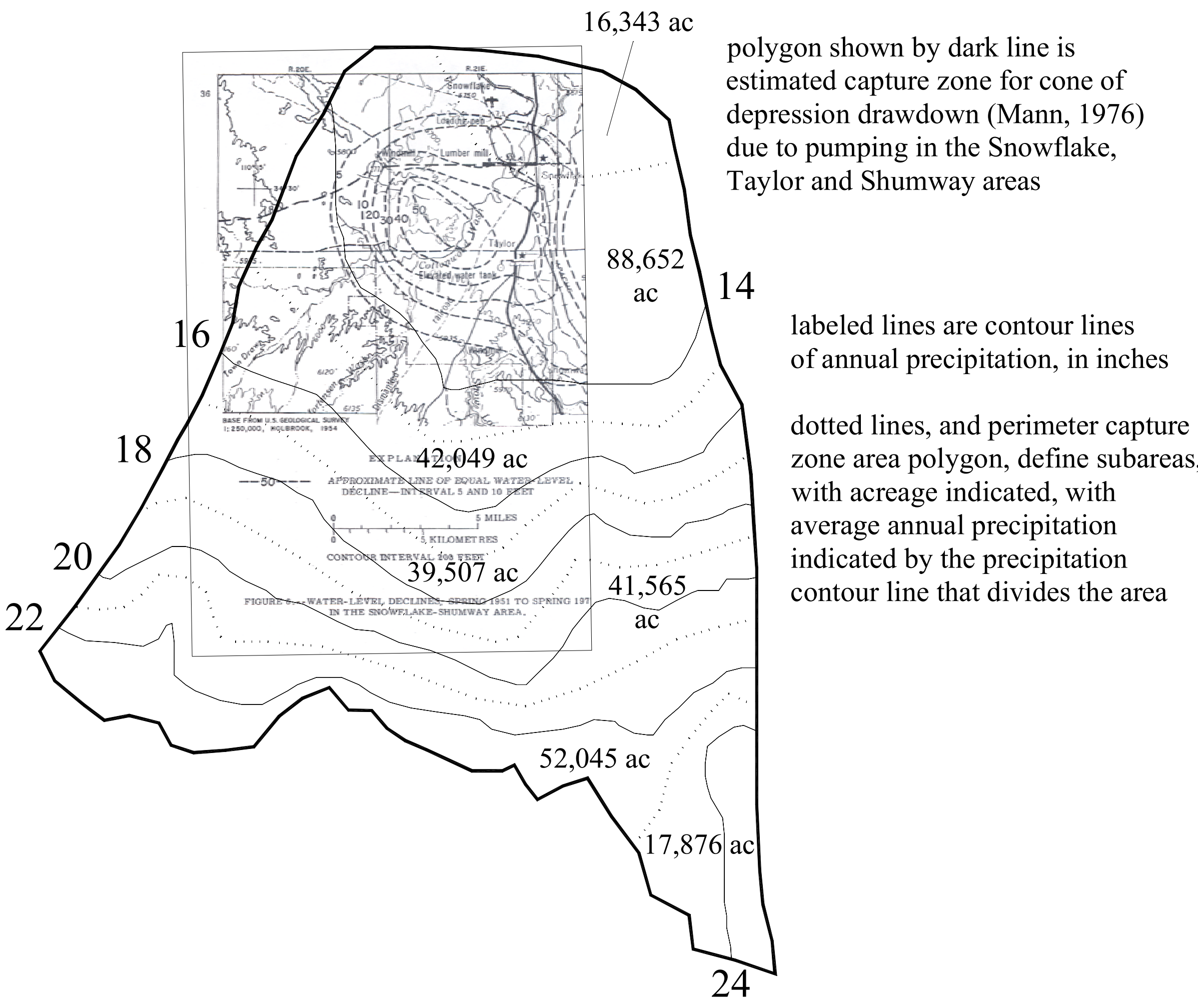
              CONVERGENCE TOLERANCES...
              Maximum Iterations=    30
              Min. TW tolerance =    .01 ft
              Max. TW tolerance =    .01 ft
              Min. HW tolerance =    .01 ft
              Max. HW tolerance =    .01 ft
              Min.  Q tolerance =    .10 cfs
              Max.  Q tolerance =    .10 cfs
```

Appendix 4

Empirical Estimates of Recharge – Supporting Documentation



Map showing areas of constant annual precipitation in the portion of the Show Low Creek watershed that is tributary to Lone Pine dam.



Map showing areas of constant annual precipitation in the portion of the Show Low Creek watershed that is the estimated approximate capture zone for ground water flow to the regional ground water pumping center in Snowflake/Taylor/Shumway.